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POLITECNICO DI TORINO

Doctorate school

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XXVI cycle

Final Dissertation

Vulnerability analysis in an Early Warning System for drought

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April 2014

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ABSTRACT

Early Warning Systems (EWS) for drought are often based on risk models that do not, or marginally, take into account the vulnerability factor. The multifaceted nature of drought (hydrological, meteorological, and agricultural) is source of coexistence for different ways to measure this phenomenon and its effects. The mentioned issue, together with the complexity of impacts generated by this hazard, causes the current underdevelopment of drought EWS compared to other hazards.

In Least Developed Countries, where drought events causes the highest numbers of affected people, the importance of correct monitoring and forecasting is considered essential. Existing early warning and monitoring systems for drought, produced at different geographic levels, provide only in a few cases an actual spatial model that tries to describe the cause-effect link between where the hazard is detected and where impacts occur. Integrate vulnerability information in such systems would permit to better estimate affected zones and livelihoods, improving the effectiveness of produced hazard-related datasets and maps.

In fact, the need of simplification and, in general, of a direct applicability of scientific outputs is still a matter of concern for field experts and early warning products end-users. Even if the surplus of hazard related information produced on the occasion of catastrophic events has, in some cases, led to the creation of specific data-sharing platforms, the conveyed meaning and usefulness of each product has not yet been addressed. The present work is an attempt to fill this gap which is still an open issue for the scientific community as well as for the humanitarian aid world.

The present study aims at conceiving a simplified vulnerability model to embed into an existing EWS for drought, which is based on the monitoring of vegetation phenological parameters, produced using free satellite derived datasets. The proposed vulnerability model includes (i) a pure agricultural vulnerability and (ii) a systemic vulnerability. The first considers the agricultural potential of terrains, the diversity of cultivated crops and the percentage of irrigated area as main driving factors. The second vulnerability aspect consists of geographic units that model the strategy and possibilities of people to access marketplaces; these units are shaped on the basis of the physical accessibility of market locations in one case, and according to a spatial gravity model of market catchments in other two proposed cases. Results of the model applied to two national case studies and evaluated with food insecurity data are presented.

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I'm grateful to all my ITHACA colleagues for their backing and for making our workplace a truly pleasant, even if noisy, place. A special thanks goes to Francesca and Alessandro who strongly contributed to the realization of this work.

I eventually thank my family, none of them knows what I have exactly been doing, but it was kind of them trying to ask about progress on every Sunday luncheon.

I do thank persons that have been beside me, for having remembered me that it was worth.

1 INTRODUCTION

Relatively recently, the attention of emergency operators in the context of natural disasters has been shifted from response and relief to prevention and preparedness (UN/ISDR, 2004a). Understanding and measuring risk and vulnerability is key to disaster reduction strategies that in turn have boosted, in the last decades, the development and use of early warning and monitoring systems (UNEP, 2012).

On the one hand the need of simplification and, in general, of a direct applicability of scientific outputs is still a matter of concern for field experts and end-users of early warning products (Bailey, 2013; W Pozzi et al., 2013), though success cases can be encountered (Hillbruner & Moloney, 2012; Tschirley et al., 2004). On the other hand even if the surplus of early warning and monitoring information produced on the occasion of catastrophic events has, in previous cases[1], led to the creation of data-sharing platform[2], the conveyed meaning and usefulness of each product has not been systematically addressed nor analyzed to date.

Most of the existent global risk models are not disaster specific, especially for the case of slow-onset disasters such as drought events. Moreover, the sources and the implemented processing of data constituting those systems are often not disclosed, thus compromising their conscious and discriminating use by end-users. Despite the existence of a consistent number of early warning and monitoring systems for drought produced by a variety of actors, few cases provide an actual spatial model that tries to represent the cause-effect linkage between where the hazard is detected and where impacts occur. The present work is an attempt to fill this gap which is still an open issue for the scientific community as well as for the humanitarian aid world.

The scientific community has a central and critical role in providing specialized input to assist governments and communities in developing effective early warning systems. Scientific expertise is fundamental for risk management support in a variety of ways: i.e. analyzing natural hazard risks facing communities, designing of scientific and systematic monitoring and warning services, allowing data exchange and eventually translating scientific or technical information into comprehensible messages in order to disseminate understandable warnings to those at risk (UN, 2006).

Until now risk assessment has been predominantly concerned with hazards, for which there are relatively good data resources and considerable progress have been made. However after having understood how adverse weather affects food crops and pasture (i.e. the hazard term of a drought risk equation), the next step is to define and map the interactions between hazards and people vulnerable to food insecurity (Bohle, Downing, & Michael, 1994; Eriyagama, Smakhtin, & Gamage, 2010; Wilcox, Kassam, Syroka, &

[1] http://horn.rcmrd.org/
[2] http://data.worldbank.org/data-catalog/open-data-for-the-horn

Cousins, n.d.). Unfortunately progress made towards the identification and measurement of social, economic and environmental factors that increase vulnerability are inadequate. As a result social science data can be difficult to obtain and even when these data are available they remain underutilized for various reasons (UN, 2006). World summits for disaster reduction and resilience building, held in the last decade, have stressed the importance of developing systems of indicators that measure risk of and vulnerability to disasters both at national and subnational level; the use of recognized indicators would help decision-makers to estimate the impact of disasters on the societal, economic and environmental spheres and to disseminate the warnings (UN/ISDR, 2005). Risk experts have previously stated (Birkmann, 2006a; UN/ISDR, 2004b) that the efforts to develop new methodologies for measuring risk and vulnerability, and to spread the knowledge of the existent ones, are to be made by the international community though the responsibility for the application of disaster and vulnerability reduction strategies belongs to individual countries. In particular when one considers drought, risk analysis should address the fact that indirect losses is symptomatic of the paramount role of vulnerability as a contributing factor to determine these losses (UNDP, 2004); the mediating role of the economy and society in determining drought-related impacts have become undeniable (Sen, 1981). Previous studies (Below, Grover-Kopec, & Dilley, 2007) that dealt with assessing hazard impacts have raised the attention on the fact that, especially for drought, a few features determine the complexity of risk measurement: the presence of vulnerable societal assets, the indirect nature of losses, the crucial role of vulnerability in determining those losses and the difficult nature of drought hazard itself.

The present research tries to address the above-mentioned issues by designing and implementing a simplified vulnerability model to embed into the ITHACA vegetation anomaly monitoring system. One of the ambitious goal of this work is thus to translate the meaning of the purely environmental hazards (based on the analysis of NDVI seasonal anomalies) into ready-to-use food security alerts. The final alert maps should convey easy and unmistakable concepts. The driving idea is to use a set of vulnerability indicators, both environmental and socio-economic, in order to weight the hazard alerts in a way to improve the readiness of the map already produced and to attach further meaning related to food insecurity potential.

The present document is structured as follows: a context for drought risk analysis, along with an overview of possible impacts and the description of the early warning system targeted by the present research, is provided in Chapter 2; a literature review of existing models for vulnerability integration in drought monitoring systems is exposed in Chapter 3; data and methodology used for the creation of the simplified vulnerability model is provided in Chapter 4, together with the model application to two case studies; in Chapter 5 the outputs, obtained by having applied the model to the case studies, are compared to evaluation data, both qualitative and quantitative, and the results are discussed; the last section (CONCLUSIONS AND FURTHER DEVELOPMENTS) is committed to final conclusions and general evaluation of the research.

2 THE DROUGHT THREAT

This chapter sets the general context of drought as hazard in which the simplified vulnerability model, final aim of the research, was developed. Most accepted definition will be given for drought itself, for risk and vulnerability. The ITHACA vegetation anomaly monitoring system will be also briefly exposed, as well as the drought impacts which the model aims at detecting and representing (i.e. the food security).

Drought has equally hit developed and developing countries in the past century and keeps on threatening diverse nations worldwide (see Figure 1 for an outlook of the drought and famine occurrences registered by countries in the last three decades of the ninetieth century). In particular in regions where the climate variability is consistent (e.g. semi-arid regions of Africa) drought events have arisen recurrently, especially in recent decades (Glantz, 1987) and have been associated with both human and economic losses: agricultural and livestock failures, drinking water supply shortages, outbreaks of epidemic disease and food insecurity for millions (International Federation of Red Cross and Red Crescent Societies, 2006; International Research Institute for Climate and Society, 2005; Slim, 2012). Similarly, in developed countries, drought takes an economically important nature; for example in the United States, this hazard is associated with losses varying from 6 to 8 billion dollars annually (Federal Emergency Management Agency, 1995).

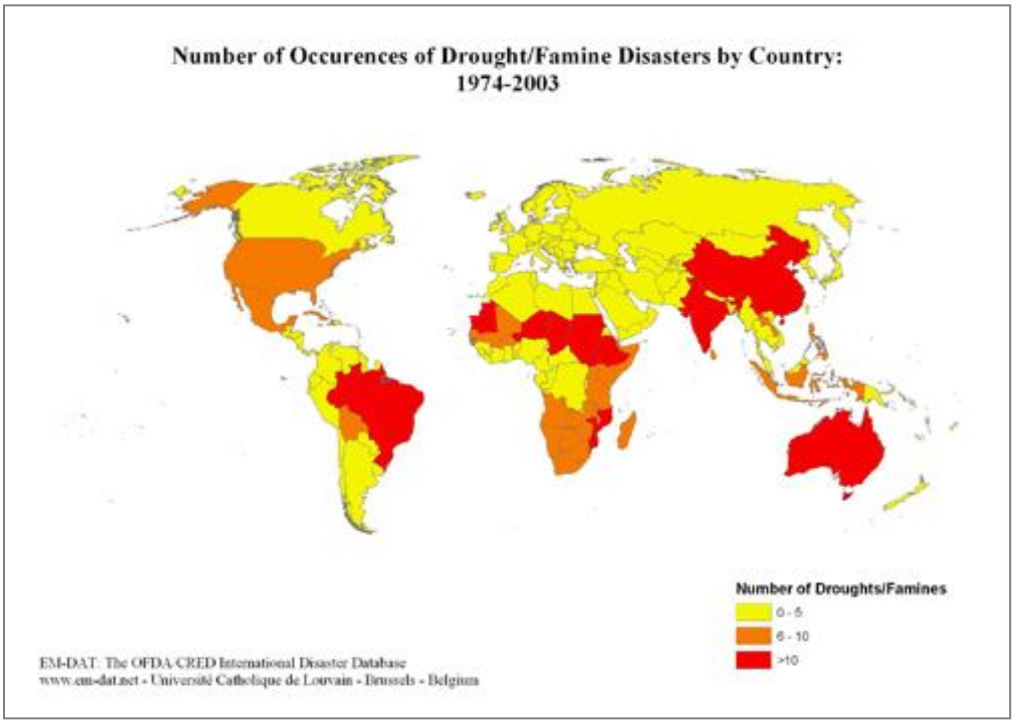

Figure 1 World view of the number of drought occurrence in the period 1974-2003 (source EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be – Université Catholique de Louvain – Brussels – Belgium.).

2.1 Drought general concepts and definitions

As early as in 1967 Yevjevich stated that widely diverse views of drought definitions are one of the principal obstacles to investigations of droughts. The issue of drought definition is longstanding and has definitely not been resolved until now (Redmond, 2002). That is drought definitions are numerous and vary depending on the variable used to describe the drought, which is a complex phenomenon that can be defined from several perspectives (Wilhite & Glantz, 1985). However a widely accepted way to define drought is through the estimation of its three components: duration, magnitude and severity (Below et al., 2007; Dracup, Lee, & Paulson, 1980).

A list of most used drought definitions and statements is provided in the following. The paragraph will offer a broad context in which to set the present study.

2.1.1 American Meteorological Society definition

The Glossary of the American Meteorological Society[3] defines:

- **Drought** as "a period of abnormally dry weather sufficiently long enough to cause a serious hydrological imbalance."
- **Agricultural drought** as "conditions that result in adverse crop responses, usually because plants cannot meet potential transpiration as a result of high atmospheric demand and/or limited soil moisture."
- **Hydrological drought** as "prolonged period of below-normal precipitation, causing deficiencies in water supply, as measured by below-normal streamflow, lake and reservoir levels, groundwater levels, and depleted soil moisture."
- **Socio-economic drought**: where the effects of the previous three conditions begin to affect human economic activity and cause problems for people living in affected regions.

2.1.2 UNCDD definition

Article 1 of the United Nations Convention to Combat Desertification (UNCCD)[4] defines drought as "the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems".

2.1.3 NDMC definition

The American National Drought Mitigation Center (NDMC) provided a way to define drought in terms of typologies. Droughts are thus classified as meteorological, agricultural, hydrological, and socio-economic inter-related events (see Figure 2). The duration component of the event is the main driver of the transition process from a type of drought to another, which implies the outbreak of various impacts.

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[3] http://glossary.ametsoc.org/wiki/Main_Page

[4] http://www.unccd.int/en/about-the-convention/Pages/Text-Part-I.aspx

Definitions of drought typologies identified by the NDMC are provided in the following[5]:

- **Meteorological drought** is defined usually on the basis of the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region.
- **Agricultural drought** links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity. Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of final yield. However, if topsoil moisture is sufficient for early growth requirements, deficiencies in subsoil moisture at this early stage may not affect final yield if subsoil moisture is replenished as the growing season progresses or if rainfall meets plant water needs.
- **Hydrological drought** is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., streamflow, reservoir and lake levels, groundwater). The frequency and severity of hydrological drought is often defined on a watershed or river basin scale. Although all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system. Hydrological droughts are usually out of phase with or lag the occurrence of meteorological and agricultural droughts. It takes longer for precipitation deficiencies to show up in components of the hydrological system such as soil moisture, streamflow, and groundwater and reservoir levels. As a result, these impacts are out of phase with impacts in other economic sectors. For example, a precipitation deficiency may result in a rapid depletion of soil moisture that is almost immediately discernible to agriculturalists, but the impact of this deficiency on reservoir levels may not affect hydroelectric power production or recreational uses for many months. Also, water in hydrologic storage systems (e.g., reservoirs, rivers) is often used for multiple and competing purposes (e.g., flood control, irrigation, recreation, navigation, hydropower, wildlife habitat), further complicating the sequence and quantification of impacts. Competition for water in these storage systems escalates during drought and conflicts between water users increase significantly.

[5]http://drought.unl.edu/DroughtBasics/TypesofDrought.aspx

- **Socioeconomic** definitions of **drought** associate the supply and demand of some economic good with elements of meteorological, hydrological, and agricultural drought. It differs from the aforementioned types of drought because its occurrence depends on the time and space processes of supply and demand to identify or classify droughts. The supply of many economic goods, such as water, forage, food grains, fish, and hydroelectric power, depends on weather. Because of the natural variability of climate, water supply is ample in some years but unable to meet human and environmental needs in other years. Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply.

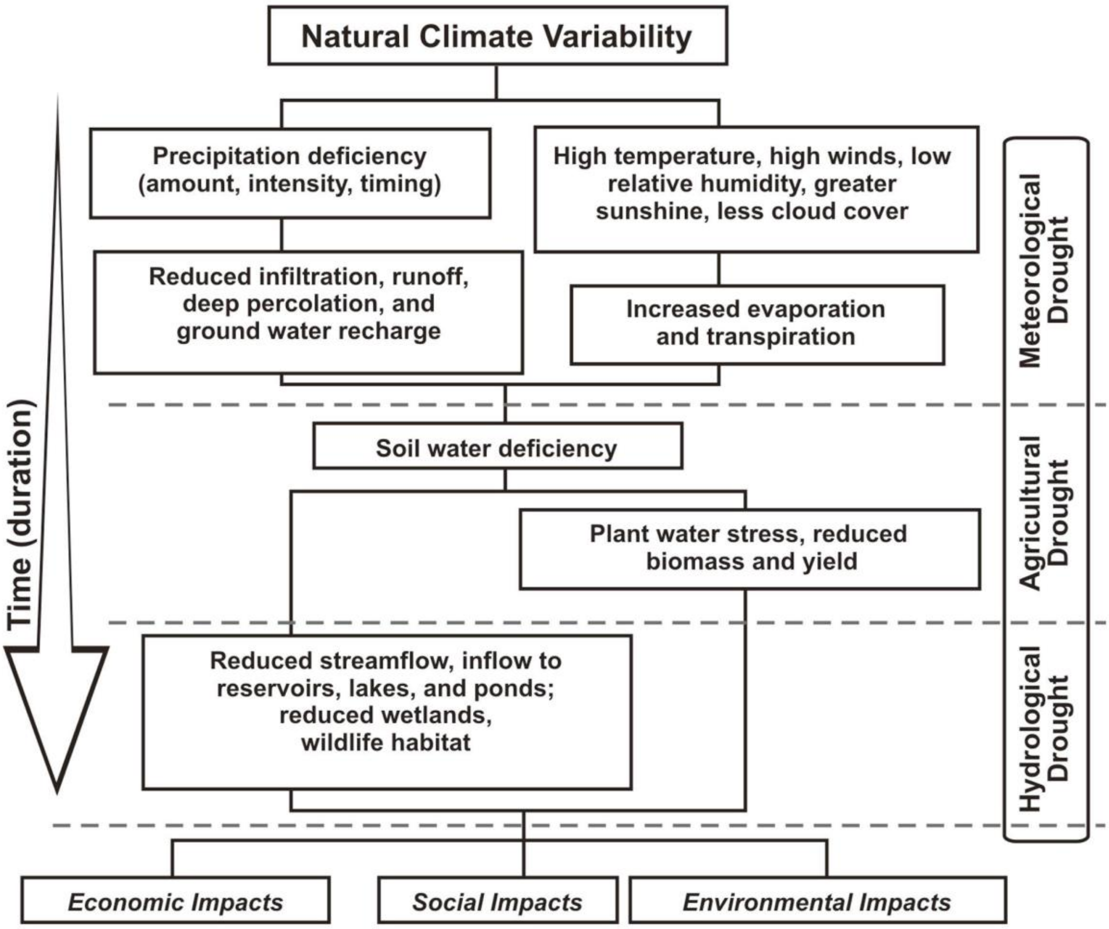

Figure 2 Relationship between meteorological, agricultural, hydrological and socio-economic drought (National Drought Mitigation Center, University of Nebraska-Lincoln, USA).

2.2 Hazard, vulnerability and risk general concepts

Bryant (1991, 2005) ranked hazard events based on their characteristics and impacts which included the degree of severity, the length of event, total areal extent, total loss of life, total economic loss, social effect, long-term impact, suddenness, and occurrence of associated hazards. It was found that drought stood first based on most of the hazard characteristics except for the suddenness and the associated hazards ones. Other natural hazards, which followed droughts in terms of their rank, are tropical cyclones, regional floods, earthquakes, and volcanoes. Moreover, droughts rank first as well among all natural hazards when measured in terms of the number of people affected (Hewitt, 1997; Obasi, 1994).

However, even if drought as a risk has rightly deserved the attention of the scientific community in the last decades (Dai, 2011; Heim, 2002; Mishra & Singh, 2010; William Pozzi, Cripe, Heim, Brewer, & Sheffield, 2011; Redmond, 2002), the difficulties in the depiction of drought risk are not lesser than those encountered in the definition of the drought itself.

2.2.1 UN/ISDR definitions

The United Nations secretariat of the International Strategy for Disaster Reduction (UN/ISDR) defined **hazard** as "a potentially damaging physical event, phenomenon and/or human activity, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation"[6].

The potential disaster losses in terms of lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period, are defined as disaster **risk** (UN/ISDR, 2009). The degree of **vulnerability** of a region depends on the environmental and social characteristics of the region and is measured by the inhabitants' ability to anticipate, cope with, resist, and recover from the occurred disaster (UN/ISDR, 2009).The risk associated with a disaster for any region or group is a product of the exposure to the natural hazard and the vulnerability of the society to the event. By consequence, drought risk is based on a combination of the frequency, severity, and spatial extent of drought events (the physical nature of the considered hazard) and the degree to which a population or activity is vulnerable to the effects of drought (UN/ISDR, 2009).

The same agency defined the **coping capacity** as "a combination of all strengths and resources available within a community or organization that can reduce the level of risk, or the effects of a disaster"[7].

2.2.2 Vulnerability and resilience

It is widely accepted that even though we are commonly dealing with vulnerability, a unique scientific concept that describes the term has not been agreed so far (Bogardi & Birkmann 2004, p. 75). The issue produce the following paradox: "we aim to measure vulnerability, yet we cannot define it precisely" (Birkmann 2006, p. 11).

Various definitions of vulnerability have been proposed in literature, a selection of the most popular ones is given in the following.

Vogel and O'Brien (2004) defined **vulnerability** as a multidimensional and differential concept which is scale dependent and dynamic.

[6]http://www.ehs.unu.edu/elearning/mod/glossary/view.php?id=8&mode=&hook=ALL&sortkey=&sortorder=&fullsearch=0&page=1
[7]http://www.unisdr.org/we/inform/terminology

The concept of vulnerability was narrowed into a **social vulnerability** definition by Cannon et. al (2003) that considers the Initial well-being of the vulnerable people, their livelihood and resilience, the degree of self and social protection and the social, political and institutional networks they are part of.

Another description of **social vulnerability** was given by Downing et al. (2006) which involves the dynamic differential exposure to multiple stresses experienced or anticipated by the different units exposed. Moreover they identified the root causes of social vulnerability in the actions and multiple attributes of human actors.

Along with vulnerability comes the concept of **resilience**; this term describes the capability of a system to maintain its basic functions and structures in a time of shocks and perturbations (N. W. Adger, Arnell, & Tompkins, 2005; Allenby & Fink, 2005). Adger (2000, p.1) defines social resilience as the ability of groups or communities to cope with external stresses and disturbances. A system is considered resilient if it can mobilize sufficient self-organization to maintain essential structures and processes within a coping or adaptation process.

2.3 The emergency management

Emergency management is defined by the UN/ISDR as follows: "The organization and management of resources and responsibilities for dealing with all aspects of emergencies, in particularly preparedness, response and rehabilitation. Emergency management involves plans, structures and arrangements established to engage the normal endeavors of government, voluntary and private agencies in a comprehensive and coordinated way to respond to the whole spectrum of emergency needs."

Figure 3 Source: Wilhite, 1999 adapted in FAO Subregional Office for Southern and East Africa Harare, 2004.

Another definition of the emergency cycle is given by Whilite (1999) and highlights how the past emphasis on crisis management has meant that society has moved from one disaster to the next without reducing the risks nor the impacts. The emergency management was therefore reduced only to a crisis management (see lower part of Figure 3) while nowadays the Disaster Risk Reduction (DRR) approach raised the importance of the risk management (upper part of Figure 3) and its mitigation and preparedness components.

The **preparedness** term includes the activities and measures taken in advance to ensure effective response to the impact of hazards, including the issuance of timely and effective early warnings and the temporary evacuation of people and property from threatened locations. **Response** is defined as the provision of assistance or intervention during or immediately after a disaster to meet the life preservation and basic subsistence needs of those people affected. It can be of an immediate, shirt term, or protracted duration. **Rehabilitation** comprises decisions and actions taken after a disaster with a view to restoring or improving the pre-disaster living conditions of the stricken community, while encouraging and facilitating necessary adjustments to reduce disaster risk. The **mitigation** phase is often included in the emergency management cycle and it involves structural and non-structural measures undertaken to limit the adverse impact of natural hazards, environmental degradation and technological hazards.

The same UN agency defined disaster risk management as follows: "The systematic process of using administrative decisions, organization, operational skills and capacities to implement policies, strategies and coping capacities of the society and communities to lessen the impacts of natural hazards and related environmental and technological disasters. This comprises all forms of activities, including structural and non-structural measures to avoid (prevention) or to limit (mitigation and preparedness) adverse effects of hazards." (UN/ISDR, 2004b)

2.4 Early warning systems

Early warning systems are part of the preparedness phase, and were defined by the International Strategy for Disaster Reduction (UN/ISDR) in 2006 as "the provision of timely and effective information, through identified institutions, that allows individuals exposed to hazard to take action to avoid or reduce their risk and prepare for effective response". Those systems are the integration of four main elements:

I. Risk Knowledge: comprehensive multi risk assessments provide essential information to set priorities both for mitigation and prevention strategies and for designing early warning systems.
II. Monitoring and Predicting: systems with these capabilities provide timely estimates of the potential risk faced by communities, economies and the environment.
III. Dissemination: communication systems are needed for delivering warning messages to the potentially affected communities. The messages need to be

reliable, synthetic and simple to be understood both by authorities and general public.

IV. Response: coordination, good governance and appropriate action plans are key points in effective early warning.

The basic idea that governs early warning is that the earlier and the more accurately it is possible to predict short and long-term risks, the more likely disasters' impact on society, economies, and environment will be managed and mitigated (UNEP, 2012).

Given the characteristics of drought, the EWS that deals with this phenomenon are more complex than those developed for other hydro meteorological hazards. Although a small number can be counted globally, examples of Early Warning and monitoring Systems for drought can be found both at global and national level (UN, 2006).

In Table 1 a list of existing global and regional early warning and monitoring systems for drought and famine is provided, including their main characteristics.

Table 1 Early Warning and Monitoring Systems for drought and famine (source: UNEP, 2012 integrated and reworked by the author).

EWS title	Producer	Geographic coverage / Spatial resolution or scale	Output type / download format	Online resource	Description
The Global Drought Monitor	BENFIELD HAZARD RESEARCH CENTRE	Global / 100 km	Monthly maps on drought current conditions /	Formerly http://drought.mssl.ucl.ac.uk/ Became unavailable on 19th November 2013	The Global Drought Monitor provides maps and short reports on countries facing exceptional drought conditions. The information is updated on a monthly basis. Hydrological drought conditions are displayed based on two drought indices, i.e. the Standardised Precipitation Index (SPI) and the Palmer Drought Severity Index (PDSI). Drought forecast is not provided.
Global Information and Early Warning System on Food and Agriculture (GIEWS)	FAO		Reports, e-mails and map of countries facing food insecurity.	http://www.fao.org/giews/english/index.htm	GIEWS monitors the food supply and demand, provides emergency response in case of human or natural induced disaster, informs policy makers with periodical reports. Reports are not specifically focused on drought conditions.
Famine Early Warning System (FIEWS)	USAID, USGS	Famine prone regions: South, East and West Africa, Central America, Caribbean, Central Asia and Middle East	Reports and maps on food insecurity / .pdf .shp	http://www.fews.net/	FEWS NET is a collaborative effort of USGS, USAID, NASA, and NOAA. FEWS net reports on food insecurity conditions and issues watches and warnings to decision makers, which are also available on the website.
U.S. Drought Monitor	USDA, NOAA, Climate Prediction Center, National Drought Mitigation Center at University of Nebraska	U.S.	Maps on drought current conditions and forecast	http://droughtmonitor.unl.edu/	The Drought Monitor provides weekly drought maps that integrates multiple indices, satellite data products and experts' opinions. Several forecast products are also provided.
DESERT	EC-JRC	Europe	Maps of soil moisture	http://desert.jrc.it/action/php/index.php?action=view&id=-1	JRC is developing, through DESERT, a European Drought Observatory (EDO) for drought

EWS title	Producer	Geographic coverage / Spatial resolution or scale	Output type / download format	Online resource	Description
					forecasting, assessment and monitoring. DESERT currently provides freely daily soil moisture maps of Europe, precipitation, vegetation and response maps.
Food Security Situation Maps	Food Security and Nutrition Group (FSNWG)	East Africa	Food security maps and monthly updates / .pdf	http://www.disasterriskreduction.net/east-central-africa/fsnwg/en/	FSNWG provides a platform for Disaster Risk Reduction in the region.

2.5 Drought and food security

Measuring the effects of a disaster implies firstly the identification and definition of what those effects are. The case of drought, a slow onset complex disaster, poses another challenge with this respect. As Peduzzi et al. stated in 2009, casualties normally attributed to droughts are typically caused by food insecurity rather than by the natural phenomenon itself. Previous studies (Birkmann & Mucke, 2011; Peduzzi et al., 2009) dealing with drought risk had pointed out that the estimation of affected people is highly complex and inaccurate to some extent compared to that of other natural disasters. In fact drought disasters typically involve a high proportion of indirect losses (Economic Commission for Latin America and the Caribbean & the World Bank, 2003). The high share of indirect losses of the total losses and the lack of visible damage outside the agriculture sector can lead to the undervaluation of the overall impacts of drought (Below et al., 2007). This is the case of drought-related mortality, for example, which is caused by drought impacts on livelihoods, contributing to reduce food intake, exacerbate migration, and creation of water and sanitation problems, leading to deterioration of health conditions, augmenting diseases, and eventually death (de Waal, 1989). As a matter of fact drought has accounted for the majority of the food shortages and food aid relief operations undertaken in the world since the 1980s (Minamiguchi, 2005). Official national statistics of drought affected population are often unavailable or based on different assumptions, which causes data to be hardly comparable in the absence of a common assessment framework. It should also be noted that emergency operations are put in place when food crisis occur, therefore the availability of a food security alert would be of help in the preparedness and response phases. In conclusion the food security status is chosen, in this study, as the ultimate indirect outcome of a drought event and thus it is investigated in order to be modeled starting from an environmental hazard assessment.

The food security condition of any households or individuals is the outcome of the interaction of a broad range of agro-environmental, socio-economic and biological factors. Therefore there is no single, direct measure of food security (WFP, 2009). A variety of proxy exists at the individual, household and national level in support of food security measurement that remains, however, an elusive concept difficult to be measured (Barrett, 2010). It has been pointed out by Peduzzi et al. (2009) that food security is not to be intended as a hazard itself, being sometimes human-induced, even if it is the main cause of the casualties following a drought event. The concept of food security, as it is widely accepted, rests on three pillars: availability, access, and utilization of food. These concepts are hierarchical, i.e. availability is necessary but not sufficient to ensure access, which is, in turn, necessary but not sufficient for effective utilization (Webb et al., 2006). As Nobel Laureate Amartya Sen wrote, "starvation is the characteristic of some people not having enough food to eat. It is not the characteristic of there being not enough food to eat. While the latter can be a cause of the former, it is but one of many possible causes" (Sen, 1981).

In the frame of this study only the availability of and the access to food were taken into consideration, the first analyzed with indicators for crop production anomalies and the second modeled considering physical accessibility to markets.

The rationale for the conception of the present vulnerability model is the possibility of producing food security outlooks without using field surveys, which are normally part of a comprehensive vulnerability and food security assessment. In Figure 4 a workflow representing a typical vulnerability assessment framework is presented. Unlike a comprehensive vulnerability assessment, the present vulnerability model starts from the hazard, i.e. the monitoring of the agro-ecological conditions (highlighted in yellow in Figure 4), and will use food availability retrieved at the household level as validation data (highlighted in light violet in Figure 4). The objective of the vulnerability model is thus to represent spatial relations and interactions between agricultural affected areas and impacted population.

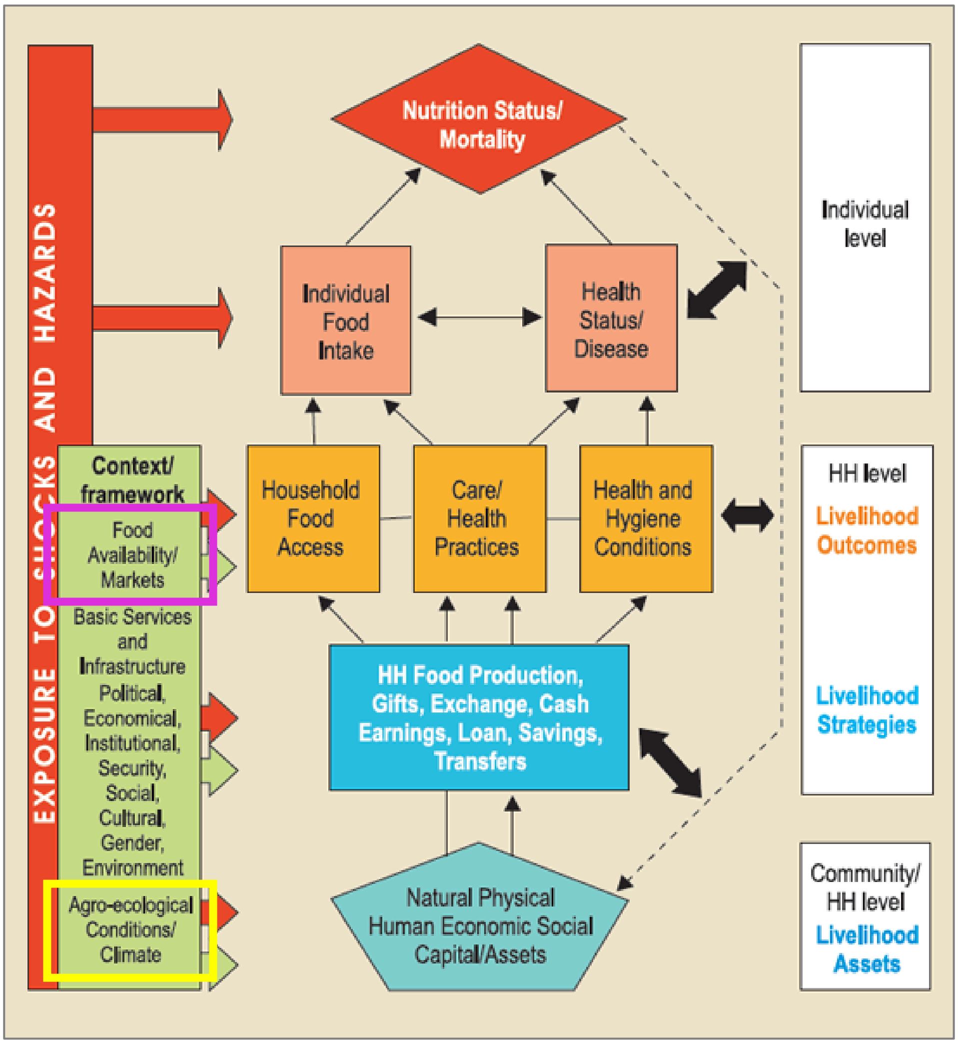

Figure 4 The Food and Nutrition Security conceptual framework (source: WFP, 2009).

2.6 ITHACA vegetation anomaly monitoring system

ITHACA developed a system for the early detection and monitoring of vegetation stress and agricultural drought events on a global scale. The system mainly relies on satellite derived data.

ITHACA system is based on the near real-time monitoring of a selection of vegetation indexes that allows the early detection of vegetation water stress conditions. That is, the monitoring of phenological parameters allows the assessment of the current vegetation productivity and its projection at the end of the growing season (Bellone, Boccardo, & Perez, 2009).

The aim of the system is the timely detection of critical conditions in vegetation health and productivity, during a vegetative growing season and at its end. By consequence the system can pinpoint agricultural areas with increased crop or pasture failure thus enabling end-users to better plan the interventions.

Currently, the development of a webGIS service suitable for the visualization and distribution of final monitoring products (near real-time and historical maps) is ongoing.

2.6.1 Data input and methodology

Vegetation monitoring procedures are based on extracting and elaborating, for each considered vegetation growing season (see Figure 5), a set of phenological parameters from the yearly NDVI function (the regular curve depicted in Figure 5) that best fits the original yearly NDVI time-series (the irregular curve depicted in Figure 5).

The vegetation phenology concerns the annual green-up, or growth, and senescence cycles of plants. Seasonal changes observed in NDVI time-series have proven useful in tracking land surface phenology and vegetation development stages, and for mapping vegetation dynamics. Specifically, produced datasets are based on the following phonological parameters:

- the Start of the Season: time when the left edge of the NDVI fitted function outreaches a user-defined threshold, that corresponds to the left minimum level (point A in Figure 5). This is the time at which seasonal photosynthetic activity begins;
- the Seasonal Small Integral: integral of the NDVI function describing the season from the Start of the Season to the End of the Season (the grey area between the fitted function and the base level, area H, in Figure 5).

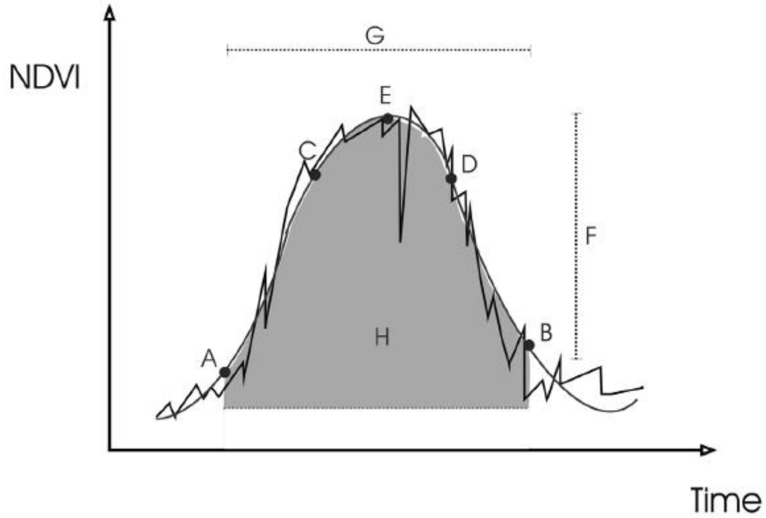

Figure 5 Diagram of NDVI/time and derived phenological parameters (A-H) for a vegetation growing season.

The basic idea behind the system developed by ITHACA is that phenological parameters for a given growing season, are related to the seasonal vegetation productivity. The parameters take into account both agricultural production and available biomass in pastoral areas. Therefore, comparing phenological values with the average values and the minimum and maximum ones computed using the whole time-series (2000 to present) of NDVI data, helps to better explain and understand the performances of the considered vegetative season (in case of historical analyses). In case of near real-time monitoring, the analysis provides an estimation of a season expected productivity.

The simple Deviation (D) and Percent Deviation (PD) from the average value are the proposed metrics to quantify the deviation of the examined vegetation season conditions from the historical normal behavior:

$$D = x - \mu_x \qquad [1]$$

$$PD = (x - \mu_x)/\mu_x \cdot 100 \qquad [2]$$

where μ_x is the historical average value of the considered phenological parameter, estimated using the whole available time-series.

Mapping the distribution of the deviation indexes [1] and [2] allows to identify areas of reduced vegetation productivity. This base information, evaluated continuously on a fortnightly basis and completed by ancillary data, such as the distribution of cultivated areas and the type of prevailing cultivation, helps to early detect critical conditions in agricultural productivity for a specific vegetative season in order to predict future crop failures and food crises.

Two outputs are produced in the framework of the ITHACA vegetation monitoring system, (i) monitoring products generated on a fortnightly basis in near real-time showing the distribution of deviation indexes for the Start of the Season and the Seasonal Small Integral parameters for the current growing season, (ii) historical maps showing the distribution of the same deviation indexes for all the vegetation growing seasons included in the 2000-2012 years (2 seasons/year, that is 2 maps/year). A description of the cited products follows.

The *Seasonal Small Integral PD imagery* describes vegetation condition for the main and secondary growing seasons for the years 2000 to present (two images per year) using the Seasonal Small Integral parameter extracted from MODIS NDVI time-series. Figure 6 shows, for instance, the distribution of the PDs (see equation [2]) for the selected phenological parameter, estimated on a pixel basis (0.05 degrees). In addition, in order to provide a more effective display of the most affected areas, raw results are also aggregated at the second level administrative boundary (Figure 7), according to a higher frequency distribution rule. As an example, in the maps reported in in Figure 6 and in Figure 7, areas where the Seasonal Small Integral parameter for the examined vegetation season has a negative deviation from the average value are shown using light orange to red colors.

It should be noted that the considered growing seasons, for the different areas of the world, refer to different months in the year, according to the specific agro-climatic zoning. For areas with two different seasons in their vegetation/crop calendar, mapped Small Integral PDs for main and secondary seasons refer respectively to the first and second season encountered from the start of the considered year; for the areas where a unique growing season is detected, only the first season is mapped (i.e. in the second season image these areas are indicated as areas where no growing season has been detected during the analyses). Besides, in the output imagery, barren areas, urban and built-up areas, evergreen/deciduous needle leaf/broadleaf forest areas, swamp vegetation, water bodies, and, in general, areas where no growing season has been detected during the analyses, are excluded from the analyses and given a specific fill value.

Moreover, raw imagery (0.05 degrees) showing the distribution of the original Seasonal Small Integer parameter (*Raw Seasonal Small Integral imagery*) for examined areas for the main and secondary growing seasons (for 2000 to present; 2 images per year) are also produced in order to allow direct vegetation productivity comparisons between two or more growing seasons specifically selected by end-users.

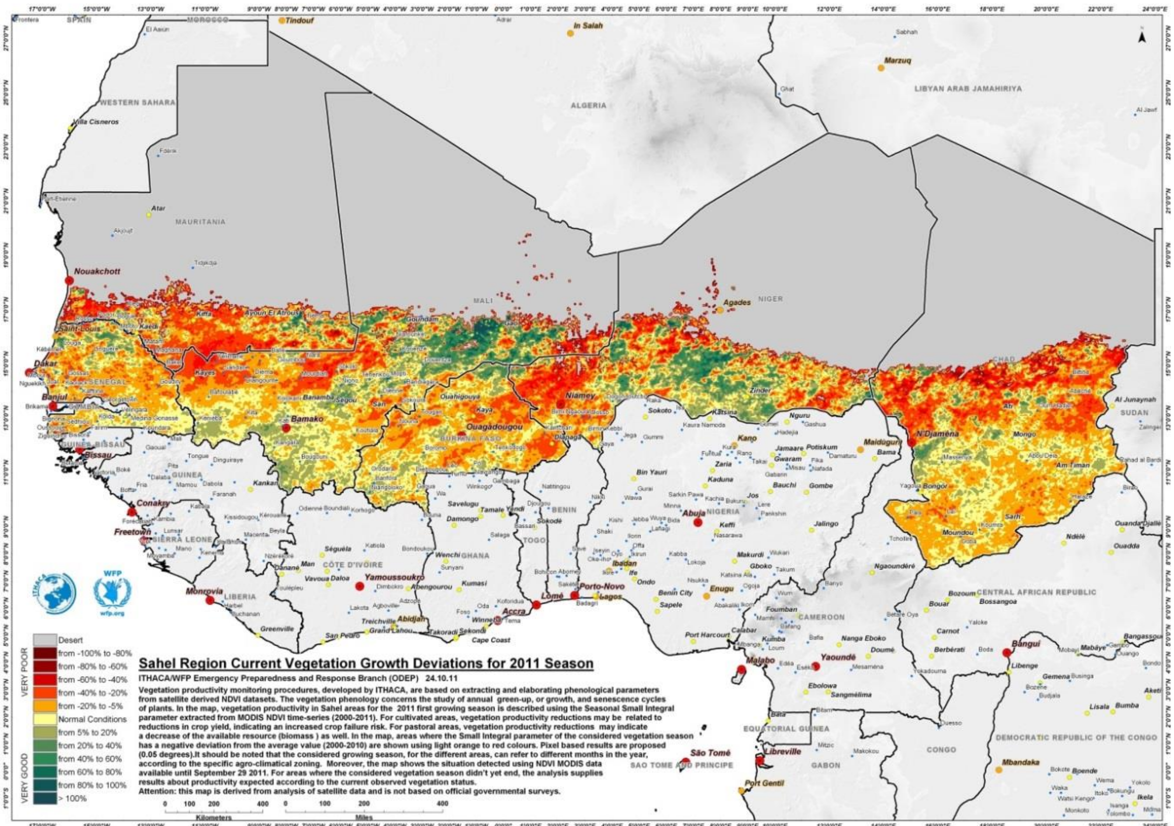

Figure 6 Pixel based output of the Percent Deviations (PDs) of the phenological parameter Seasonal Small Integral for the 2011 growing season for the Sahel area.

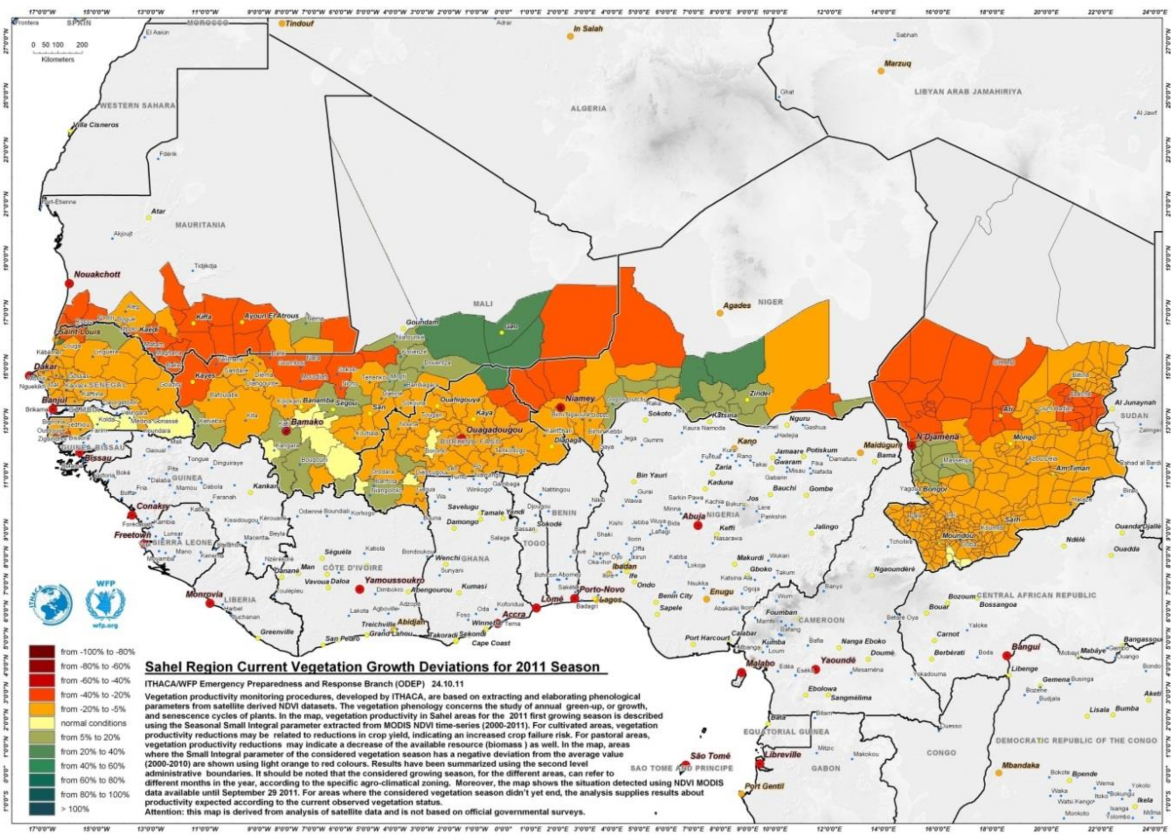

Figure 7 Aggregated on the second level administrative boundary output of the Percent Deviations (PDs) of the phenological parameter Seasonal Small Integral for the 2011 growing season for the Sahel area.

The *Start of the Season shifts D imagery* shows the shifts in the Start of the Season dates for the main and secondary growing seasons for the years 2000 to present (two images per year) estimated using MODIS NDVI time-series. Images show the distribution of the deviations D (see eq. [1]) for the selected phenological parameter, estimated on a pixel basis (0.05 degrees). In addition, the results are aggregated at a second level administrative boundaries (Figure 8) according to a higher frequency distribution rule. As an example the map in Figure 8 displays areas where the Start of the Season date for the considered vegetation season exhibits a delay with respect to the average value shown in light violet to violet. It should be noted that the Start of the Season dates for the growing seasons, estimated using the proposed procedures, are based only on satellite-derived base data, and therefore they may differ from official dates reported in crop calendars.

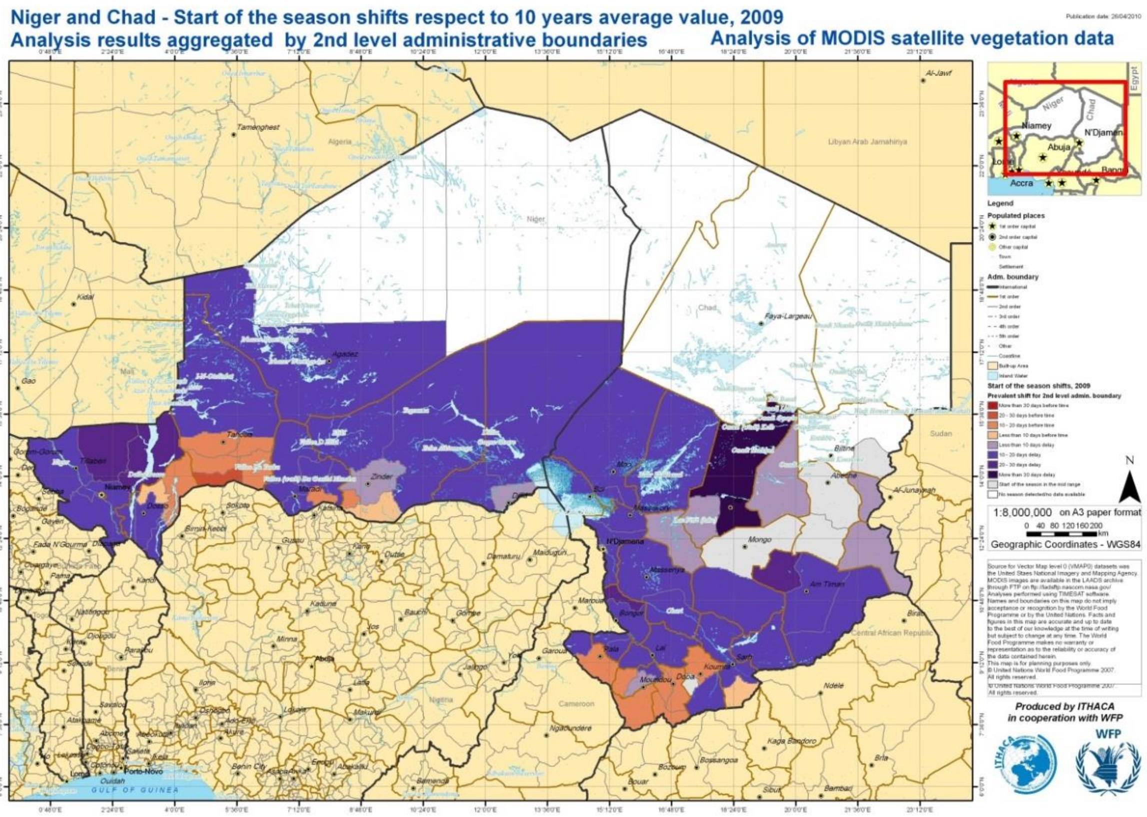

Figure 8 Map showing the Deviations (D) of the phenological parameter Start of the Season date for the 2009 growing season for the Niger and Chad areas; output aggregated on the second level administrative boundary.

2.6.2 Derived products

Value-added products/information that can be derived from base datasets are the following:

- <u>direct vegetation productivity comparisons</u>, based on raw *Seasonal Small Integral imagery*, between two or more growing seasons specifically selected. Besides, the Condition Index (CI), which provides a measure of the proximity of the considered value, or an examined year, of the selected parameter to the minimum (CI=0) and maximum (CI=1) ones, can be estimated using raw *Seasonal Small integral imagery*. The CI is expressed as:

$$CI = \frac{x - min_x}{max_x - min_x} * 100 \qquad [3]$$

where

x is the value of the phenological parameter for the examined growing season;

min_x and max_x are the minimum and maximum values of the parameter considered, extracted from the whole available historical time-series (2000 to present).

- drought historical products, that is the investigation of the historical occurrence of vegetation stress events in a region through the aggregation of the Seasonal Small Integral Percent Deviation values for selected years. This analysis allows the identification of the areas showing the greatest number of negative vegetation productivity deviations in subsequent growing seasons. For instance, areas most affected by poor vegetation growth in the selected time interval could be considered more vulnerable in case of future drought events (Figure 9). This dataset allows drought hazard identification, which is a required step in drought risk assessment and identification. Refinement though is possible by coupling historical vegetation productivity information with ancillary data, such as the distribution of cultivated areas and the type of prevailing cultivation, or the livelihood zones distribution.

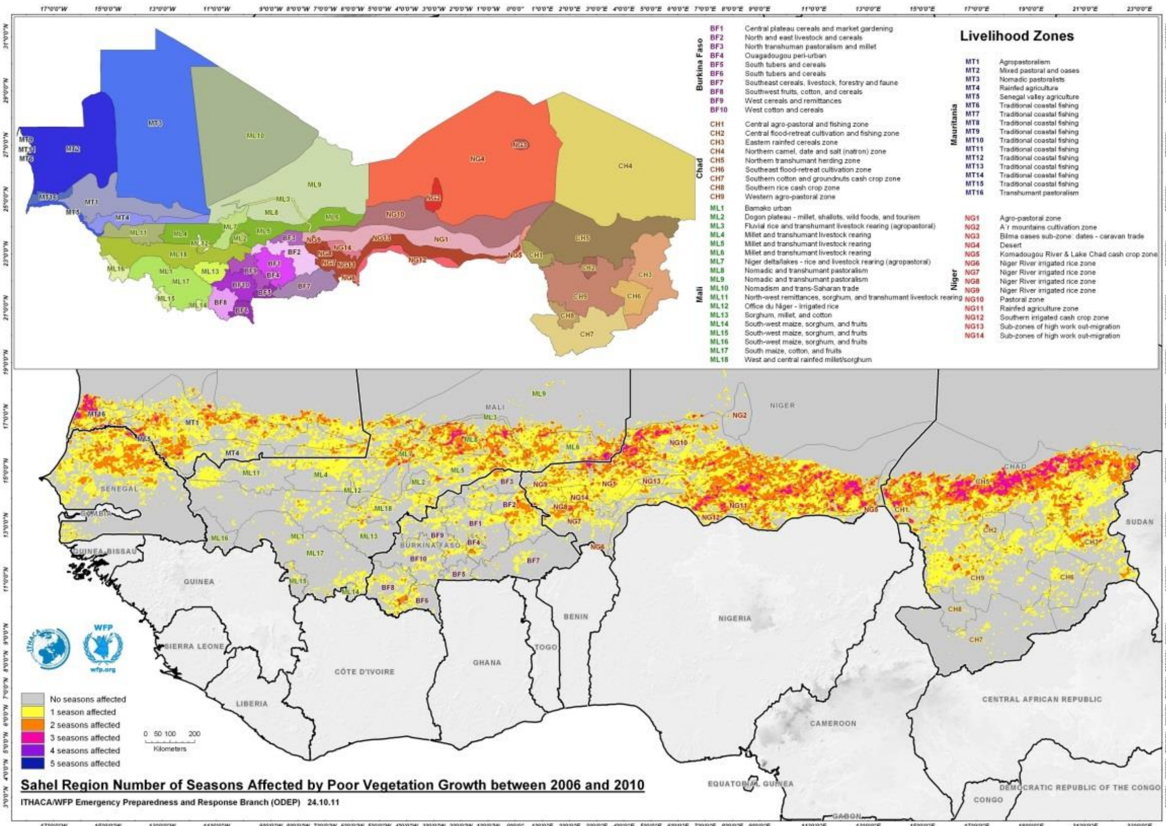

Figure 9 Map showing the number of negative vegetation productivity deviations between 2006 and 2010 in the Sahel area.

3 LITERATURE REVIEW

In this chapter a review of inspiring works is reported: (i) the existing drought monitoring and early warning systems that integrate vulnerability in one of its forms; and (ii) attempts and suggestions on what vulnerability for drought risk calculation should include. The focus of the present chapter is not to provide a list of existing drought EW and monitoring system and indexes to calculate drought hazard, but to examine the studies that targeted vulnerability as a key factor in drought risk measurement.

The category (i) includes global systems that are both drought specific and multi-risk.

At first place the WorldRiskIndex, developed by the United Nations University Institute for Environment and Human Security (Bonn, Germany), should be mentioned. The WorldRiskIndex indicates, for each country, the probability that this will be affected by a disaster. Globally available data are used to calculate the disaster risk for the countries analyzed. In the framework of the WorldRiskIndex, disaster risk is conceived as interactions among natural hazards and social, political and environmental factors. This index, in addition to exposure analysis, focuses on the vulnerability of the population, which is subdivided into susceptibility, capacities to cope with and to adapt to future natural disasters. The risk is then seen as a function of exposure and vulnerability and is calculated per aggregation at country level. The WorldRiskIndex consists of indicators subdivided into four components (Figure 10): exposure to natural hazards (i.e. earthquakes, storms, floods, droughts and sea level rise); susceptibility (i.e. a function of public infrastructure, housing conditions, nutrition and the general country economic status); coping capacities (i.e. a function of governance, disaster preparedness and early warning, medical services, social and economic security); and adaptive capacities to future natural disasters (Birkmann & Mucke, 2011). The World Risk Report provides a global ranking of the country risk index and a detailed description of the applied methodology and data used (Birkmann & Mucke, 2011).

Figure 10 Scheme of the concept of the WorldRiskIndex (source: Birkmann & Mucke, 2011).

Although aiming at mapping the risk globally (see Figure 11), the World Risk Report reports a case study on a sub-national level (i.e. Indonesia case study). It must be mentioned that, in the calculation of exposure, drought exposed individuals as retrieved by CRED EM-DAT database, were only half-weighted, with respect to other hazards, due to the peculiarity of the drought hazard in showing its effects. The latter assumption, according to the author, justifies the present attempt to concentrate on single hazard risk models, especially for drought.

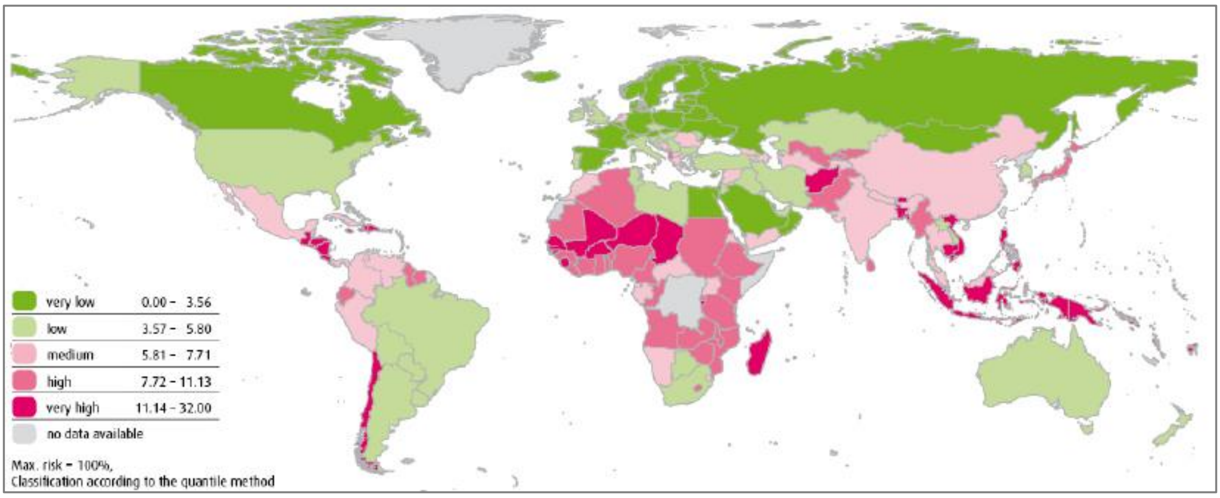

Figure 11 WorldRiskIndex as result of the exposure and vulnerability (source: Birkmann & Mucke, 2011).

The WorldRiskIndex was certainly inspired by the work of Peduzzi et al. (2009) which was equally aimed at conceiving a worldwide valid multi risk index, i.e. the Disaster Risk Index (DRI), to the profit of the United Nations Development Programme (UNDP). The mandate from UNDP was actually to analyze potential links between vulnerability to natural hazards and levels of development of nations. The DRI was the first model to prove a statistical evidence of the mentioned link at the global scale. The DRI takes into account, among the others, the drought risk, which is calculated considering the following indicators: physical exposure, Gross Domestic Product (GDP) per capita and the percentage of arable land; the last two indicators accounts for vulnerability in the DRI model for drought.

Among the few existing global drought specific monitoring system a well renowned one is the Fews Net (Famine Early Warning Systems Network) project[8]. The Fews Net is a provider of early warning and analysis on acute food insecurity. In order to do so it constantly monitors vegetation and meteorological drought indicators (satellite-based) and couples them with field survey data such as those relative to markets and trade and nutrition. The Fews Net provides food security assessments and outlooks on the basis of projected likely scenarios. These outputs are provided at subnational levels for a set of countries food-insecurity prone or otherwise strategic. The most useful characteristic of those food security assessments and outlooks is the fact that they are classified according to a widely recognized frame of classification, i.e. the Integrated Food Security Phase Classification (IPC 2.0)[9] scale, that allows the data to be easily understandable by a

[8] http://www.fews.net/
[9] http://www.fews.net/our-work/our-work/integrated-phase-classification

wide public of operators and users (for more details on the IPC scale refer to paragraph 4.4.1) and comparable among countries.

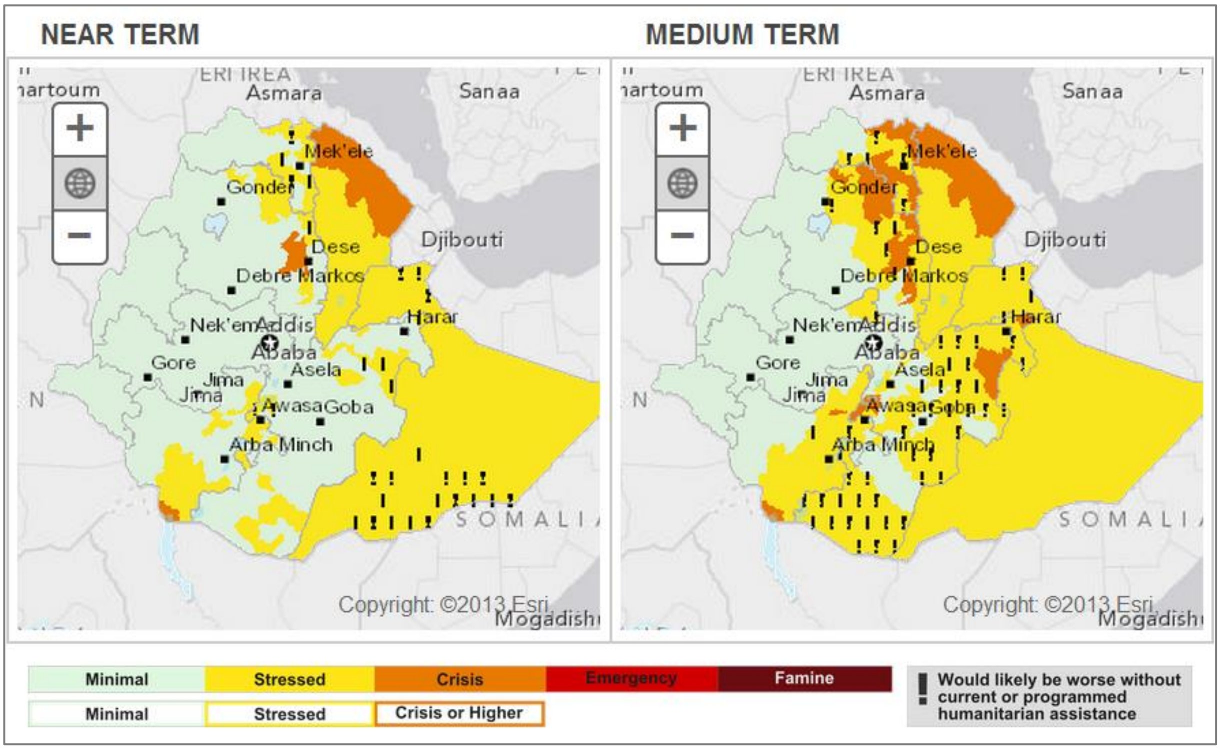

Figure 12 Few Net food security outlook, near and medium term, for Ethiopia (source www.fewsnet.net accessed on February 18th 2014).

An original work on drought mapping was realized by Eriygama et al. (2009), which arose from the observation that a scarcity of attempts to extensively describe and represent various aspects and impacts of drought, as an independent natural disaster and as a global complex phenomenon, exist. The work contains a review of quite a large set of indexes of both drought hazard and types of vulnerability to drought; these indexes were mapped by the authors at a global extent when possible on a 0.5 grid cell basis, or aggregated at country level. Of particular interest are the vulnerability indexes that are proposed, one per each of the drought vulnerability aspects (i.e. infrastructure, biophysical and socioeconomic vulnerability indexes). Two examples of drought vulnerability indexes mapped are provided in Figure 13 and in Figure 14. The study concluded that more effort should be put in quantifying and indexing vulnerability globally, with a view also of considering climate change in the medium and long run.

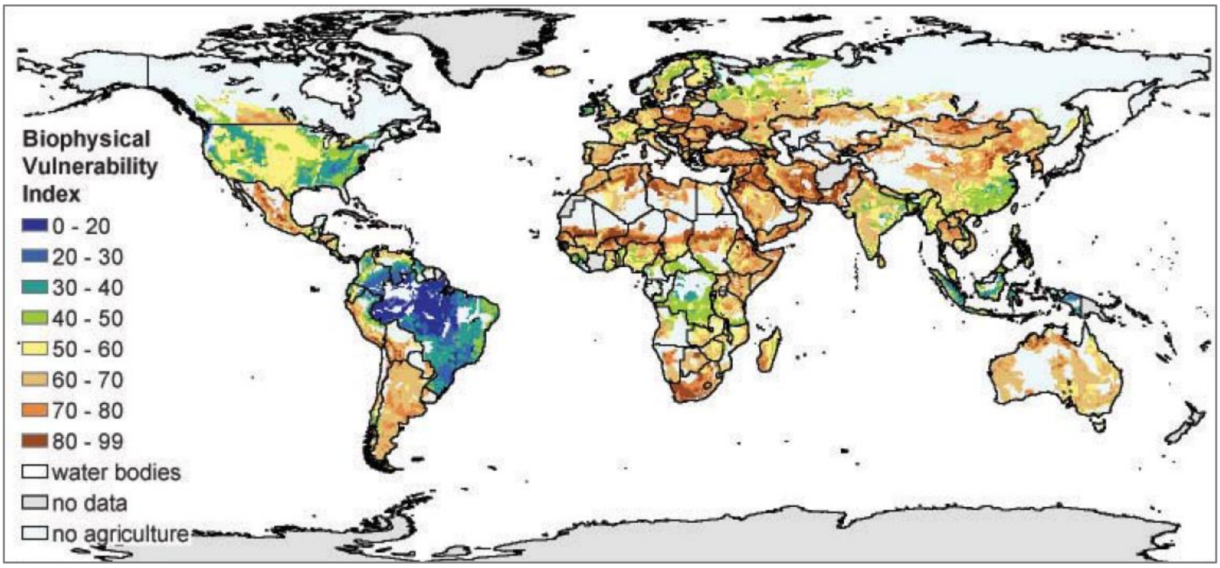

Figure 13 Biophysical Vulnerability Index based on mean annual surface runoff, mean annual groundwater recharge, soil depth and soil degradation severity within 0.50 grid cell (source: Eriygama et al., 2009).

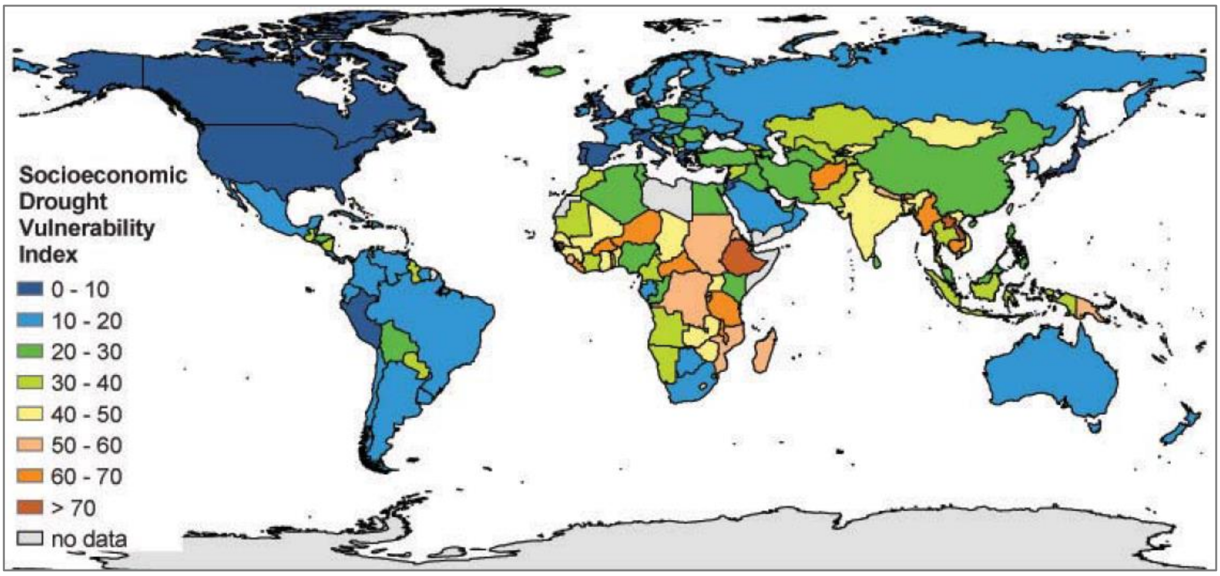

Figure 14 Socioeconomic Drought Vulnerability Index based on the crop diversity of individual countries and their dependence on agriculture for income and employment generation (source: Eriygama et al., 2009).

An attempt of drought geospatial indexes mapping for Africa was developed by Miller et al. (2002). The authors provided a framework for mapping a list of original indexes, thus explaining the relationships existing among them and deriving additional features (i.e. called surfaces) to be used for modeling natural risks (an example of a proposed index is provided in Figure 15). The proposed indexes are mainly based on existing global open-source datasets, processed in a GIS environment, with the final aim of describing vulnerability (Cicone, Parris, Way, & Chiesa, 2003).

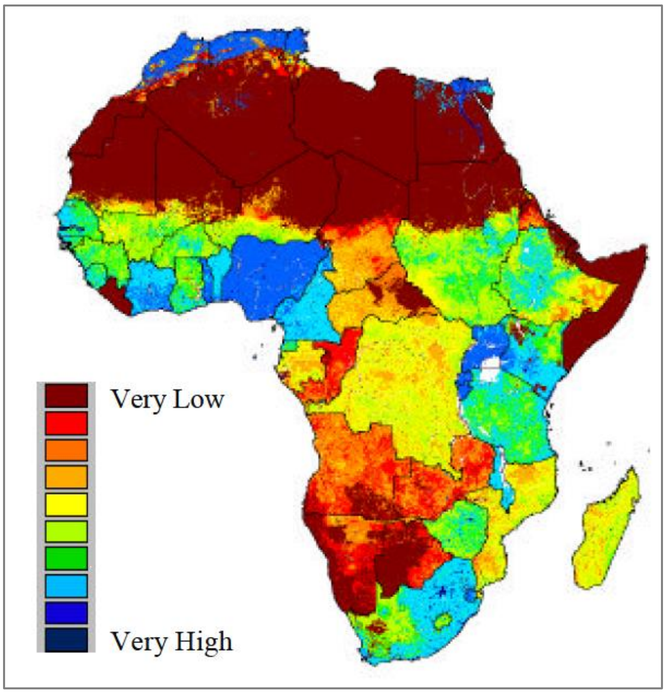

Figure 15 Disaggregated GDP on the basis of the distribution of urban areas, as captured by the nightlights, and of LandScan population density dataset (source: Miller et al., 2009).

A recently developed system is likely to be seen as a turning point for risk specific monitoring systems. The Africa RiskView (Wilcox et al., n.d.) is a system that aims at quantifying and monitoring weather-related food security risk in Africa. The system is deployed on a web-platform that focuses only on drought to date, but it is planned to be integrated with other weather risks (i.e. flood). The platform allows to translate satellite-based rainfall and derived environmental indexes into drought impacts on agricultural production and grazing. By overlaying these impact data with vulnerability information, the software also produces a broad estimate of the affected population and of the emergency response cost. The software was conceived and developed mainly by WFP and its partners for the profit of the Africa Risk Capacity adherents, which are interested in the quantification of risk costs for stipulating agricultural assurances in the African continent. For the above-mentioned reasons the Africa RiskView platform is not publicly accessible, therefore its use is limited to accredited users.

On a continental basis the Global Monitoring of Environment and Security (GMFS)[10] is also available for Africa, so far. GMFS is an activity started by the European Space Agency (ESA) under the joint ESA and European Commission (EC) Global Monitoring for Environment and Security (GMES) initiative. GMFS is conceived for end-users from regional and national organizations whose mandate is agricultural monitoring for food security and early-warning of food crises. The project provides an open-access catalogue of meteorological and agricultural data, both satellite-derived and field survey based, and of derived environmental indexes and reports.

[10] http://www.gmfs.info/ accessed on 19th February 2014

Concerning food security indicators and mapping, interesting national case studies have been proposed by the NASA Socioeconomic Data and Applications Center (SEDAC)[11]. The purpose of the work (i.e. Poverty and Food Security Case Studies) was to provide high spatial resolution subnational estimates of poverty and food security (see a case study example for Kenya in Figure 16). The availability of data is limited to a few numbers of case studies and is not up to date, having the project ended in 2002.

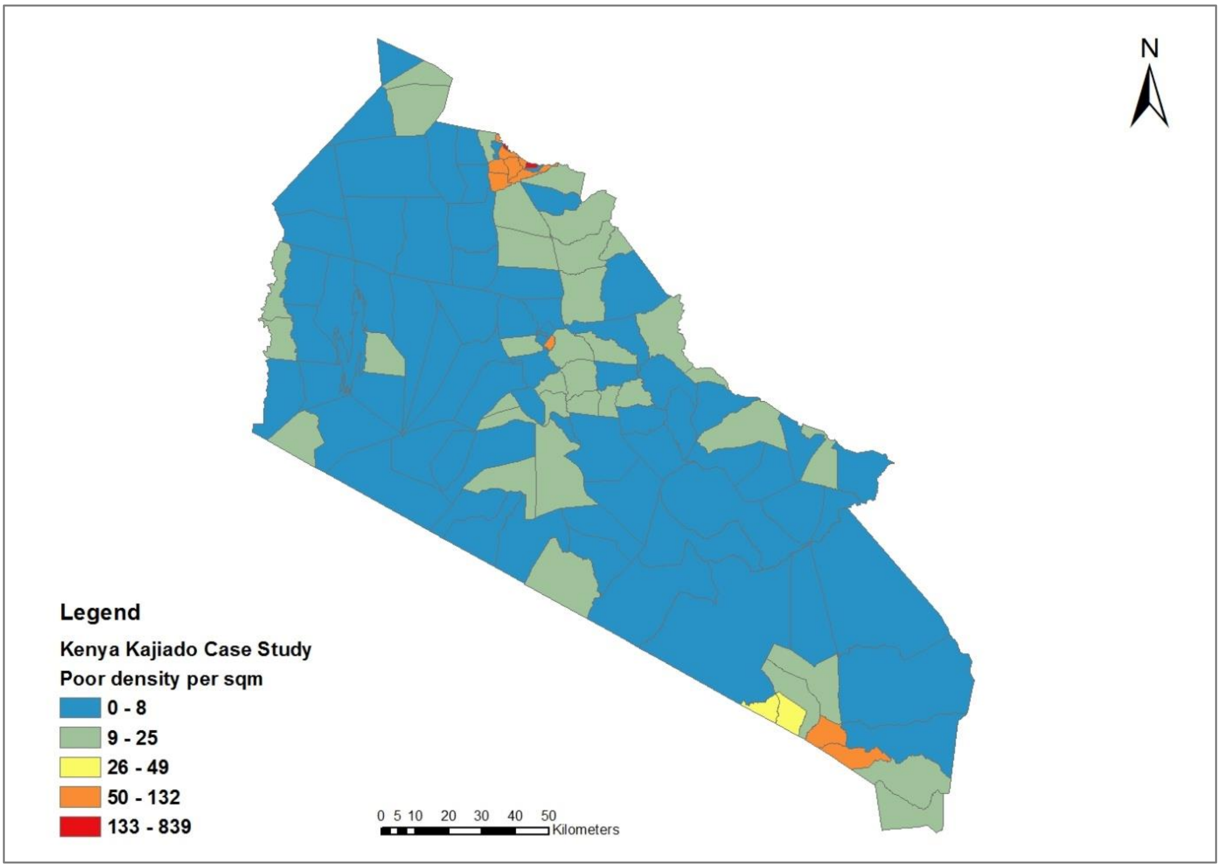

Figure 16 The map shows the number of poor people per km^2 in the Kenya Kajiado district of Kenya (source: International Livestock Research Institute, 20040115, Kenya Kajiado Case Study: ILRI, Nairobi).

Other suggestions for drought risk indicators were found in the work of Julich (2006) which was focused on drought impact assessment on households. The author states that the origin of disparities in drought vulnerability resides in the household level. Examples of proposed, but non applied, indicators are the diversity of crops and the number of economical active persons in relation to total household components.

A useful inventory of drought national warning and mitigation systems for Africa was provided by Nyabeze (2012) in the framework of the project "improved Drought Early Warning and FORecasting to strengthen preparedness and adaptation to droughts in Africa" (DEWFORA)[12]. The inventory covers a dozen countries of Western, Eastern and Southern Africa, for each of those providing a description of local warning indicators for

[11] http://sedac.ciesin.columbia.edu/data/set/povmap-poverty-food-security-case-studies accessed on 19th February 2014

[12] http://www.dewfora.net

drought as well as institutional ones. In the framework of the same EU-funded project an interesting report is found on the definition of a methodology for assessing drought vulnerability across Africa (Garrote, 2012). It is there stated that "…in the context of a drought early warning system, the focus on vulnerability may prove to be very effective since it includes the evaluation of the capacity to anticipate and compensate the adverse effects of drought." (Garrote, 2012). The importance of defining drought indicators that are tailored on the type of drought impact which has to be analyzed is also reported in the document; the statement furnished to the author of the present study a valid argument for investigating vulnerability to be coupled with a specific early warning system.

4 DATA AND METHODS

In this chapter the data and the methodology used to implement the proposed vulnerability model are presented. The first two paragraphs are devoted to a detailed description of the datasets and of the components of the model. The third paragraph provides an analysis of the case studies to which the model was applied. The fourth paragraph presents the data, qualitative and quantitative, used to perform an evaluation of the outcomes of the model applied to the selected case studies.

4.1 Data inventory

A variety of data were investigated for the purpose of the present study. A literature research was performed in order to identify datasets used for existing early warning systems and risk models. A data review was needed to analyze data characteristics and their fit to use in the presented study. In particular the reference data catalogue realized in the framework of the European Commission GMES initial operations was extensively used (Boccardo et al., 2012).

Only a subset of datasets that had been contemplated in the first place was eventually used for building the model indicators. Investigated datasets belong to the following main categories:

- Land Cover
- Administrative boundaries
- Water and agriculture
- Hydrography
- Elevation
- Population
- Development

Considering the aims of the present work and of the ITHACA drought monitoring system itself, two requirements were considered essentials for a dataset to be selected: the global extent and the absence of access and use constraints.

The Table 2 resumes the main characteristics of the dataset investigated for the proposed simplified vulnerability model. Highlighted in light yellow the datasets that were eventually considered appropriate for building the indicators of the proposed model.

Table 2 Data description.

DATABASE TITLE	DATABASE ALT TITLE	DATABASE PRODUCER	DATASET NAME	DATASET TYPE	DATASET SCALE / AGGREGATION LEVEL	DATABASE LAST EDITION / EDITION DATE	Update frequency	ONLINE RESOURCE ACCESS
World Income Inequality Database	WIID	UNU-WIDER			National	V2.0c May 2008		http://www.wider.unu.edu/research/Database/en_GB/database/
CIA World Factbook		CIA		.pdf, .jpg, and textual	National		weekly	https://www.cia.gov/library/publications/the-world-factbook/index.html
CountrySTAT		FAO	various (e.g food production, land cover, etc.)	.xls	Administrative level 1		yearly or less frequently	http://www.fao.org/economic/ess/CountrySTAT/en/ http://www.CountrySTAT.org/default.aspx
FaoSTAT		FAO	various (e.g food production, trade, food balance)	.xls	National		yearly or less frequently	
LandScan Global Population 2008 Database	LandScan 2008	Oak Ridge National Laboratory (ORNL) for the United States Department of Defense	United States Bureau of the Census; National Geospatial-Intelligence Agency (NGA); The Global Administrative Unit Layers (GAUL) dataset, implemented by FAO within the EC FAO Food Security for Action Programme.	Raster (ESRIgrid)	Cell size: 0.008333333 degrees (nearly 1 km^2 at equator, 30 arc-sec)	2009		http://www.ornl.gov/sci/landscan/

DATABASE TITLE	DATABASE ALT TITLE	DATABASE PRODUCER	DATASET NAME	DATASET TYPE	DATASET SCALE / AGGREGATION LEVEL	DATABASE LAST EDITION / EDITION DATE	Update frequency	ONLINE RESOURCE ACCESS
GTOPO30		USGS EROS Data Center		Raster	Spatial Resolution: 30 arc-sec (1 km at the equator)	1996		http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30_info
AquaSTAT	GMIA	Universitat Bonn, FAO	Global map of irrigation areas (GMIA)	Raster (ASCIgrid; ESRIgrid)	5 arc-minutes, 0.083333 decimal degrees (nearly 10 km^2 at equator)	v 4.01 2007		http://www.fao.org/nr/water/aquastat/irrigationmap/index10.stm
Land Use System Database	FAO and UNEP		lus.tif	Raster	5 arc-min (about 9 km at equator)	v1.1 (30.06.2010)		http://www.fao.org/nr/lada/index.php?option=com_content&view=article&id=154&Itemid=184&lang=en http://www.fao.org/geonetwork/srv/en/main.home
World Development Indicators	WDI	World Bank	GDP	Table (.xls)	National		yearly	http://databank.worldbank.org/ddp/home.do?Step=12&id=4&CNO=2
Nighttime Lights of the World		NOAA		Raster		2003		http://sabr.ngdc.noaa.gov/ntl/?2003&global
FAO AgroMaps		FAO		.xls	Administrative level 1 and 2 occasionally	v2.5 2009		http://kids.fao.org/agromaps/
	GLOBE	NOAA	GLOBE	.bil	1 km			
Global Land Cover Map	GlobCover	ESA			300 m (0,00278 decimal degrees)	v2.3 2009		http://due.esrin.esa.int/globcover/

DATABASE TITLE	DATABASE ALT TITLE	DATABASE PRODUCER	DATASET NAME	DATASET TYPE	DATASET SCALE / AGGREGATION LEVEL	DATABASE LAST EDITION / EDITION DATE	Update frequency	ONLINE RESOURCE ACCESS
Harmonized World Soil Database	HWSD	Land Use Change and Agriculture Program of IIASA (International Institute for Applied System Analysis LUC) and FAO; ISRIC-World Soil Information, the Joint Research Centre of the European Commission (JRC), and the Institute of Soil Science, Chinese Academy of Sciences.	Main data: hwsd.bil, hwsd.blw, hwsd.hdr, HWSD.mdb; supplementary data: sq1.asc, sq2.asc, sq3.asc, sq4.asc, sq5.asc, sq6.asc, sq7.asc	Raster and tables	30 arc-second (1 km at the equator)	Version 1.1 - Mar, 2009		http://www.fao.org/nr/land/soils/harmonized-world-soil-database/download-data-only/en/
Vector Smart Map Level 0	NGA		Transportation, industry, settlements	Vector	1:1.000.000	5° ed. - 2000		http://geoengine.nima.mil/ftpdir/archive/vpf_data/v0noa.tar.gz http://geoengine.nima.mil/ftpdir/archive/vpf_data/v0eur.tar.gz http://geoengine.nima.mil/ftpdir/archive/vpf_data/v0soa.tar.gz http://geoengine.nima.mil/ftpdir/archive/vpf_data/v0sas.tar.gz
Global Irrigated area mapping	GIAM	IWMI	GIAM	.kmz	Global (10 km) and National only few Countries	v 2.0	last update with 1999 data	http://www.iwmigiam.org/info/main/index.asp

DATABASE TITLE	DATABASE ALT TITLE	DATABASE PRODUCER	DATASET NAME	DATASET TYPE	DATASET SCALE / AGGREGATION LEVEL	DATABASE LAST EDITION / EDITION DATE	Update frequency	ONLINE RESOURCE ACCESS
GeoData		UNEP	Agriculture value added - Percent of GDP	.csv, .html, .xls, .shp	Different aggregation level (National, Sub-regional, Regional)	2011		http://geodata.grid.unep.ch/
		UNEP	Gross Domestic Product	.csv, .html, .xls, .shp	Different aggregation level (National, Sub-regional, Regional)	2011		http://geodata.grid.unep.ch/
		UNEP	Gross Domestic Product - Purchasing Power Parity	.csv, .html, .xls, .shp	Different aggregation level (National, Sub-regional, Regional)	2011		http://geodata.grid.unep.ch/
Global Assessment of Human-induced Soil Degradation	GLASOD	ISRIC		.dhp	1:10.000.000	1987-1990		http://www.isric.org/projects/global-assessment-human-induced-soil-degradation-glasod
	LADA	FAO-UNEP	GLADIS	Images	National and subnational	n.a.		http://www.fao.org/nr/lada/index.php?option=com_content&view=article&id=185&Itemid=168&lang=en
Global Agro-Ecological Zones	GAEZ	FAO	Various (land cover, productivity, etc.)	.asc	5 arc-minutes, 0.083333 decimal degrees (nearly 10 km^2 at equator)	2012		http://www.fao.org/nr/gaez/en/

DATABASE TITLE	DATABASE ALT TITLE	DATABASE PRODUCER	DATASET NAME	DATASET TYPE	DATASET SCALE / AGGREGATION LEVEL	DATABASE LAST EDITION / EDITION DATE	Update frequency	ONLINE RESOURCE ACCESS
Africover		FAO	Multipurpose Landcover database	.shp	1:200.000	2002 (on Landsat 1994-1999 data)		http://www.africover.org/system/user/user.php?PHPSESSID=c1ca6e93b412b75ae4b8e6175962b780
			Towns	.shp	1:100.000	2002		http://www.fao.org/geonetwork/srv/en/main.home
Global ADMinistrative Areas	GADM	Different US universities and research institutes	Global Administrative Areas - gadm_v1_lev0, Global Administrative Areas - gadm_v1_lev1	.shp	n/a	v 2.0/January 2012	Continuous	http://www.gadm.org/
Global Administrative Unit Layers	GAUL	The GAUL is an initiative implemented by FAO within the EC-FAO Food Security Programme funded by the European Commission	g2008_2006_1 (Level1); g2008_20006_2 (Level2) (global datasets). Lower levels (level 3, level 4, level5), when available, are supplied on individual country base.	.shp		GAUL 2009/2009	Yearly	http://www.fao.org/geonetwork/srv/en/main.home;

4.2 Conceptual model

The challenge of the present work mainly resides in the measurement of the vulnerability that has to be coupled with drought hazard values (Angeluccetti & Perez, 2013). As stated in 2006 by Birkmann, the concept of vulnerability is multidimensional and often ill-defined, therefore it is difficult to define a universal measurement methodology or to reduce this concept to a single equation (Birkmann, 2006b; T. Downing, 2004).

In the present study a vulnerability model was conceived specifically to be used for a NDVI based drought hazard. Given the nature of the hazard itself, constituted of seasonal values available at pixel level (i.e. 5 km spatial resolution), an Agricultural Vulnerability layer was built with the same spatial resolution in order to be superimposed to the hazard one. Pixels of the two layers are thus geographically coherent and this permit to weigh the hazard according to the identified levels of Agricultural Vulnerability (i.e. one to one relation).

With the aim of providing a meaningful alert with respect to the population potentially impacted, a layer composed by units to which attach an alert level has been built. These units should identify homogeneous areas from the point of view of access to markets and food availability. People inhabiting a specific unit are supposed to be equally impacted by a hazard hitting the cropland found in the same area.

In the end Final Alerts are the product of the relations existing among the hazard stressing the crops (on the left in Figure 17), the Agricultural Vulnerability which is a characteristic of the agricultural land (in the middle in Figure 17), and the Risk Surface identifying the population that will be impacted (on the right in Figure 17). The meaning of the Agricultural Vulnerability and of Risk Surface layers are provided in the following paragraph.

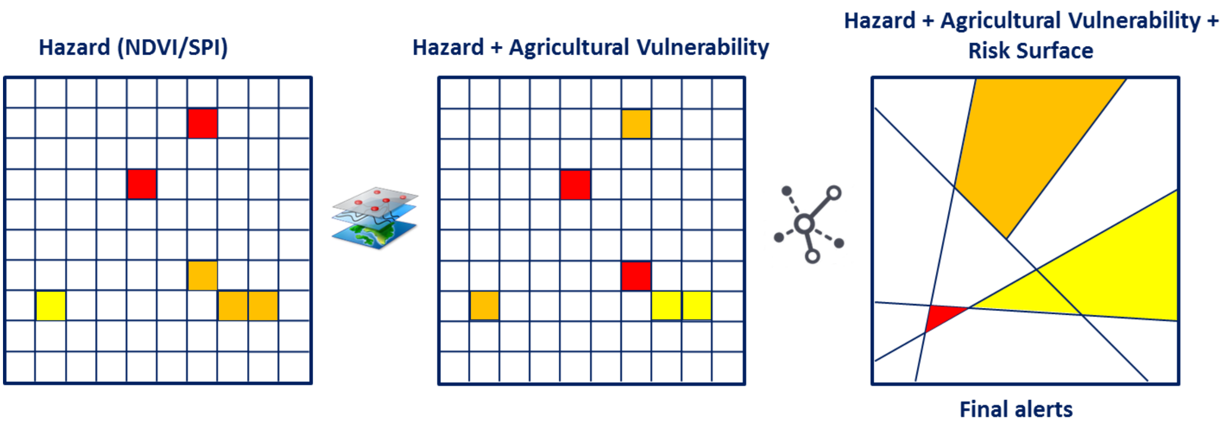

Figure 17 Conceptual model.

4.2.1 Applied methodology

Three different raster layers serve as basis of the implemented methodology:

1. a drought **hazard** layer;
2. an **agricultural vulnerability** layer;

3. a **risk surface** layer.

The output of the model is called **final alert** layer, and it furnishes a value linked to the food security conditions of a determined area.

The process and the data sources used for creating the above mentioned layers will be explained in the following paragraphs.

The model has been applied to two national **case studies**, Niger and Mozambique, in order to evaluate its goodness through the comparison with food security truth data, preferably aggregated at sub-national level.

The **hazard** layer (1) is produced in near real-time, on a pixel basis, observing the deviation of a selected vegetation phenological parameter from the average value obtained considering the whole time-series (2000 to present). The considered hazard has an "environmental" nature and it is meaningful only over agricultural (or pastoral) areas. The same concept is valid for the produced agricultural vulnerability dataset. The hazard layer is already produced by the ITHACA drought detection system (see 2.6 for more details); in the framework of this study only the *Seasonal Small Integral PD,* among the products of the considered EWS, was used as hazard value.

The **agricultural vulnerability** layer (2) serves as a weight for the hazard layer, it consists of a combination of environmental indices. It accounts for the potential agricultural productivity. The agricultural vulnerability is a raster layer of 5 km spatial resolution.
The hazard layer is superimposed to the agricultural vulnerability layer (see schema of Figure 17); each alerted pixel belonging to the hazard layer is weighted with the value of the corresponding pixel of the agricultural vulnerability layer (detail description provided in 4.2.2).

The **risk surface** layer (3) is the subdivision of the country area into risk units (i. e. market or city catchments). It consists of a raster layer with 300 m spatial resolution (see schema of Figure 17). Each weighted hazard pixel, produced by the monitoring system, belongs to a specific market catchment and thus is supposed to impact its population. In order to test different assumptions on market and city catchments, a set of three risk surface layers (see Figure 18, Risk Surface i, ii and iii) were obtained with different processes (detail description provided in 4.2.3).

The **final alert** is given per risk unit and is obtained through summing up the weighted hazard pixel values belonging to the analyzed risk unit (detail description provided in 4.2.5). The three risk surface layers, obtained coupling different indices in different ways, were then superimposed to the hazard layer, previously weighted with the agricultural vulnerability one, providing a set of final alerts (see Figure 18 Final Alert) one per each surface layer tested. This set of final alerts was produced for the selected case studies and evaluated by means of food security data. An outline of the methodology is reported Figure 18.

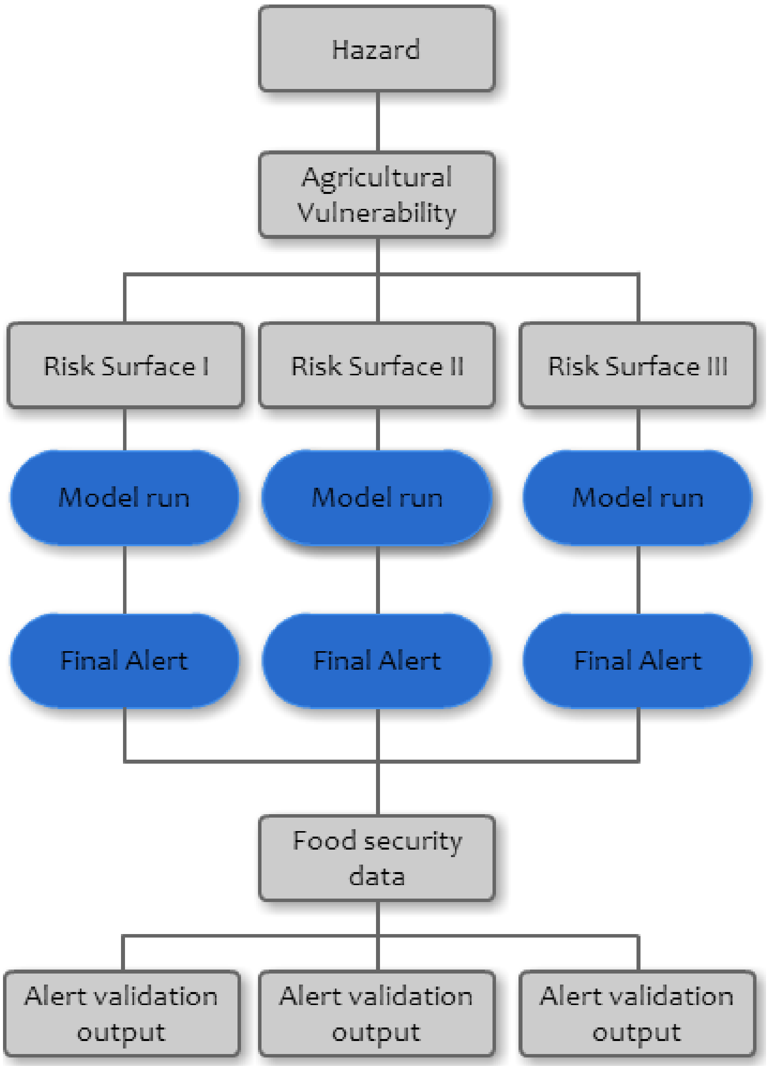

Figure 18 Methodology workflow.

4.2.2 Agricultural vulnerability

Previous studies (Bohle et al., 1994) showed that intrinsic or human induced land vulnerability can influence the amplitude of the impacts of a drought event. In particular, regions geographically subjected to the effects of climate change and where land and water resources are stressed and degraded by human pressure, are likely to be more prone to drought and drought-induced food insecurity. Therefore it was decided to build an agricultural vulnerability layer, which accounts for some of the drought impact enhancing factors, to be enclosed into the model.

The Agricultural vulnerability layer is built by considering three indicators: (i) the *soil suitability for crop production* (FAO Global Agro-Ecological Zones database[13]), (ii) the *percentage of irrigated area* (FAO Global Map of Irrigation Areas dataset[14]) and (iii) the

[13] http://www.fao.org/nr/gaez/en/
[14] http://www.fao.org/nr/water/aquastat/irrigationmap/index.stm

Crops Diversity Index (modified after Julich, 2006; based on FAO CountrySTAT administrative level 1 production database[15]).

The above mentioned indicators are combined to build the agricultural vulnerability in order to take into account, respectively: (i) the agricultural potential of soils themselves; (ii) the presence of irrigation facilities which is subjected to augment the agricultural potential; (iii) the diversification of cultivated crops, which is supposed to play an important role in the degree of vulnerability of a cropland area.

The agricultural vulnerability layer is expressed with a numeric scale ranging from 1 to 8, in which the extreme values correspond to irrelevant and very high vulnerability respectively; thus increasing values correspond to higher vulnerability.

The steps needed for the creation of the agricultural vulnerability layer are provided in the following paragraphs, in chronological order of application. The detailed description of the data used is also provided in the respective paragraphs.

4.2.2.1 Soil suitability for crop production - Step 1

The FAO Global Agro-Ecological Zones (GAEZ) database is very extensive; it comprises a vast choice of environmental datasets covering five thematic areas:

- Land and water resources;
- Agro-climatic resources;
- Suitability and potential yields for up to 280 crops/land utilization types;
- Downscaled actual yields and production of main crop commodities;
- Yield and production gaps, in terms of ratios and differences between actual yield and production and potentials for main crops.

The methodology for the achievement of the GAEZ datasets was developed by the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA) over the past 30 years.

In this study the Crop Suitability Indices (classes) were considered; the Crop Suitability index is expressed in 9 classes, from Very High Suitability to Not Suitable. The Crop Suitability Indices are part of a GAEZ subset called *Agro-ecological suitability and productivity*. These datasets have a global extent and they are downloadable in raster format (5 arc-minute or 10 km spatial resolution) under four input levels (high, intermediate, low), five water supply system types (rain-fed, rain-fed with water conservation, gravity irrigation, sprinkler irrigation and drip irrigation), per crop type (49 crops), under baseline (1961-1990) and future climate conditions.

The GAEZ website provides a comprehensive and spatially explicit database of crop production potential and related constraint factors. The rain-fed land productivity is assessed through a water-balance model in order to determine the beginning and duration of the period when sufficient water is available to sustain crop growth. Soil

[15] Find an example at http://www.CountrySTAT.org/home.aspx?c=MOZ&tr=21

moisture conditions together with other climate characteristics (radiation and temperature) are used in a robust crop growth model to calculate potential biomass production and yield. The irrigated land productivity is assessed by matching each crop growth cycle length with the period with temperatures conducive for crop growth. The calculated potential agro-climatic yields are subsequently combined with a number of reduction factors directly or indirectly related to climate (e.g., pest and diseases), and with soil and terrain conditions. The reduction factors, which are successively applied to the potential yields, vary with crop type, the environment (in terms of climate, soil and terrain conditions) and depend on assumptions regarding level of inputs/management. In order to ensure that the results of the suitability assessment relate to production achievable on a long term basis, (i) fallow periods have been imposed, and (ii) terrain slopes have been excluded when inadequate for the assumed level of inputs/management or too susceptible to topsoil erosion.

An example of GAEZ dataset is reported in Figure 19.

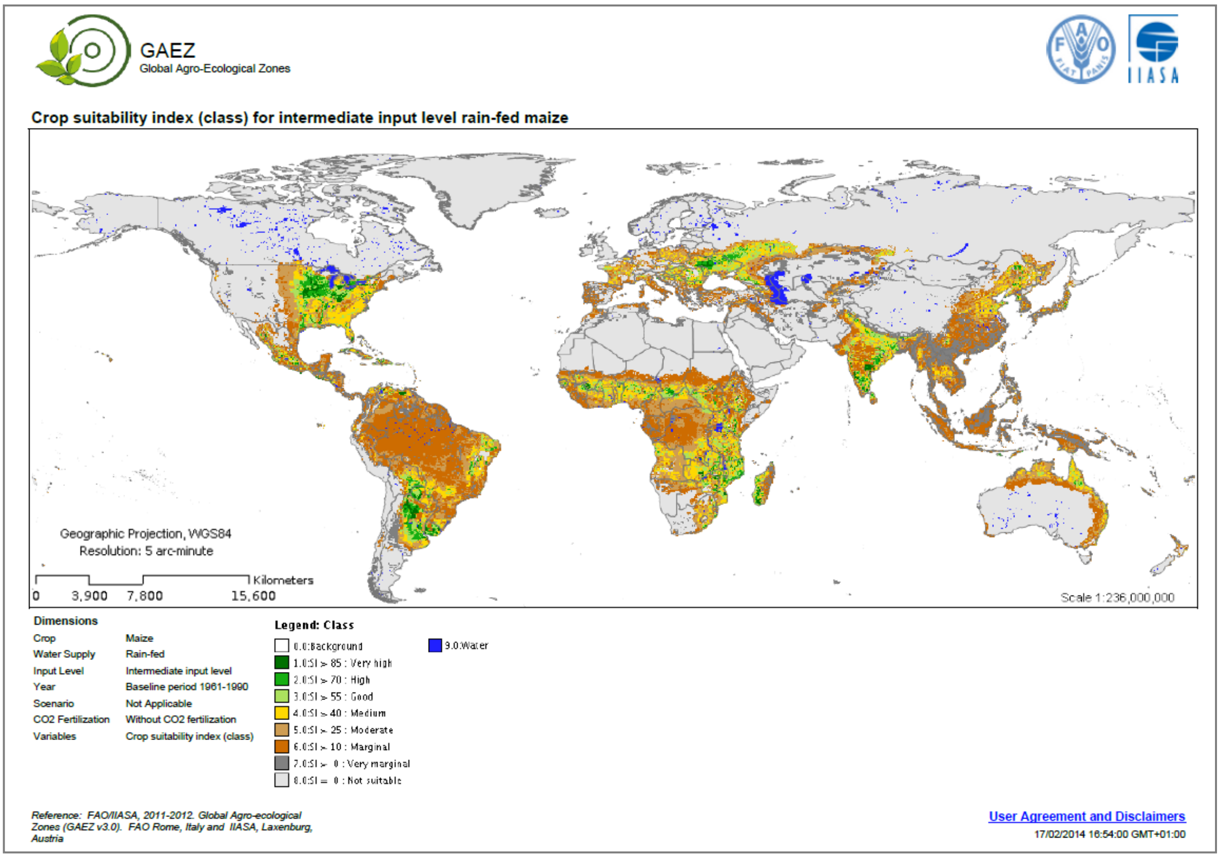

Figure 19 Example of a Crop Suitability Index for intermediate input level maize, baseline period (1961-1990).

Considering the large number of Crop Suitability Indices available and the aim to produce a country-based vulnerability model, the following considerations had to be made: in order to perform the analysis at the country extent, a subset of the global extended Crop Suitability Index was to be obtained; for a selected country the most produced crop type per administrative level 1 has been derived from the CountrySTAT administrative level 1 production database (expressed in weight and downloadable in table format[16]); the corresponding Crop Suitability Index dataset has then been retrieved from the GAEZ database (choosing by default an intermediate input level and the baseline climate conditions).

The extraction of the most produced crop per administrative level 1 was performed through a self-developed Matlab procedure (see Annex I - Matlab script for CDI). CountrySTAT is a web-based information technology system for food and agriculture statistics at the national and subnational levels. It centralizes and integrates the data coming from various sources and allows to harmonize them according to international standards. Depending on the countries considered, it gathers institutional statistical information from population census to agricultural, fisheries and livestock production. However, data aggregation level and availability vary considerably among countries. Despite the efforts made at harmonizing data, information tables are often incompatible country by country (see an example in Annex II - CountrySTAT raw data). This issue is challenging if the data are to be used in automatic procedures, therefore a manual preprocessing was needed to be performed in order to prepare the data for the analysis.

Eventually the different Crop Suitability indexes, one per each administrative level 1, were mosaicked to obtain the whole country coverage. The final product of this phase is a map showing the spatial distribution of the suitability of the terrain to produce a particular type of crop, specifically the most produced crop on a historical basis (Figure 20).

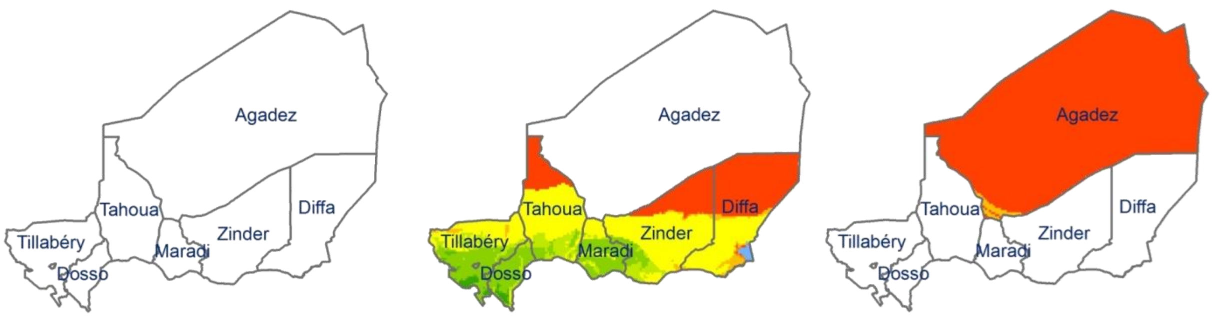

Figure 20 For each admin level I (on the left) the main cultivated crop has been calculated over the available time series. The corresponding crop suitability has been extracted from the GAEZ database and the whole country was mapped by merging different administrative suitability tiles (middle and right). Suitability increases from light green to dark red.

4.2.2.2 Global Map of Irrigation Areas - Step 2

The suitability class values obtained in step 1 (see 4.2.2.1) were revised by considering the Global Map of Irrigation Areas (GMIA) dataset.

The latest version of the map shows the amount of area equipped for irrigation around the year 2005 in percentage of the total pixel area on a raster with a resolution of 5 arc-minute (10 km at the equator) (Siebert, Henrich, Karen, & Burke, 2013). Additional map layers report the percentage of the area equipped for irrigation that was actually used for

[16] Find an example at http://www.CountrySTAT.org/home.aspx?c=MOZ&tr=21

irrigation and the percentages of the area equipped for irrigation that was irrigated with groundwater, surface water or non-conventional sources of water. The first global digital map of irrigated areas, obtained on the basis of cartographic information and FAO statistics, has a resolution of 0.5 degree and was developed in 1999 by the Center for Environmental Systems Research of the University of Kassel. The latest version of the map is reported in Figure 21.

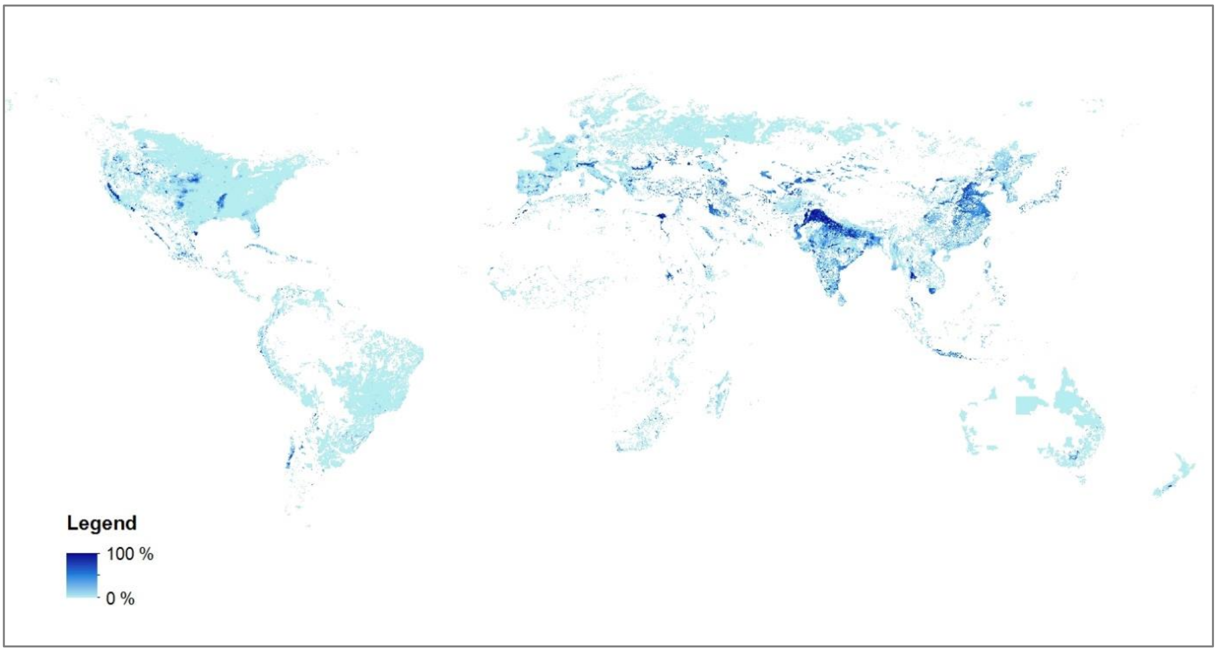

Figure 21 Global Map of Irrigation Areas version 5.0, values are expressed in percentage of the pixel occupied by irrigation systems.

The suitability layer, obtained in step 1, and the GMIA dataset were firstly superimposed. Each suitability pixel value was then multiplied by 5% of the corresponding GMIA pixel value, thus augmenting the suitability class when a considerable portion of the pixel area is identified as equipped with irrigation systems. The result of this operation is reported in Figure 22, which represents the suitability layer weighted with the percentage of irrigation area per pixel.

4.2.2.3 Crop Diversity Index - Step 3

The Crop Diversity Index (CDI) can be considered as an indicator of the resilience of the households living in the area over which is calculated, and should thus diminish the value of the agricultural vulnerability.

The Crop Diversity Index was calculated as suggested in Julich, (2006) and modified by Eriygama, Smakhtin, & Gamage, (2009) eventually reworked by the author as follows:

$$CDI = \sum P^2 \quad [4]$$

where:

P is the administrative level 1 mean production, over the available time series, of each type of crop divided by the sum of the mean total production.

The Crop Diversity Index is supposed to be calculated at the household level but, considering that large areas are being analyzed, the administrative level 1 was considered a fair compromise between a qualitative assessment and a quantitative detailed one. Smaller CDI values thus indicate higher crops diversity and consequently a lesser degree of vulnerability. A theoretical representation of the linkage existing between the CDI and the drought risk is given in Figure 23.

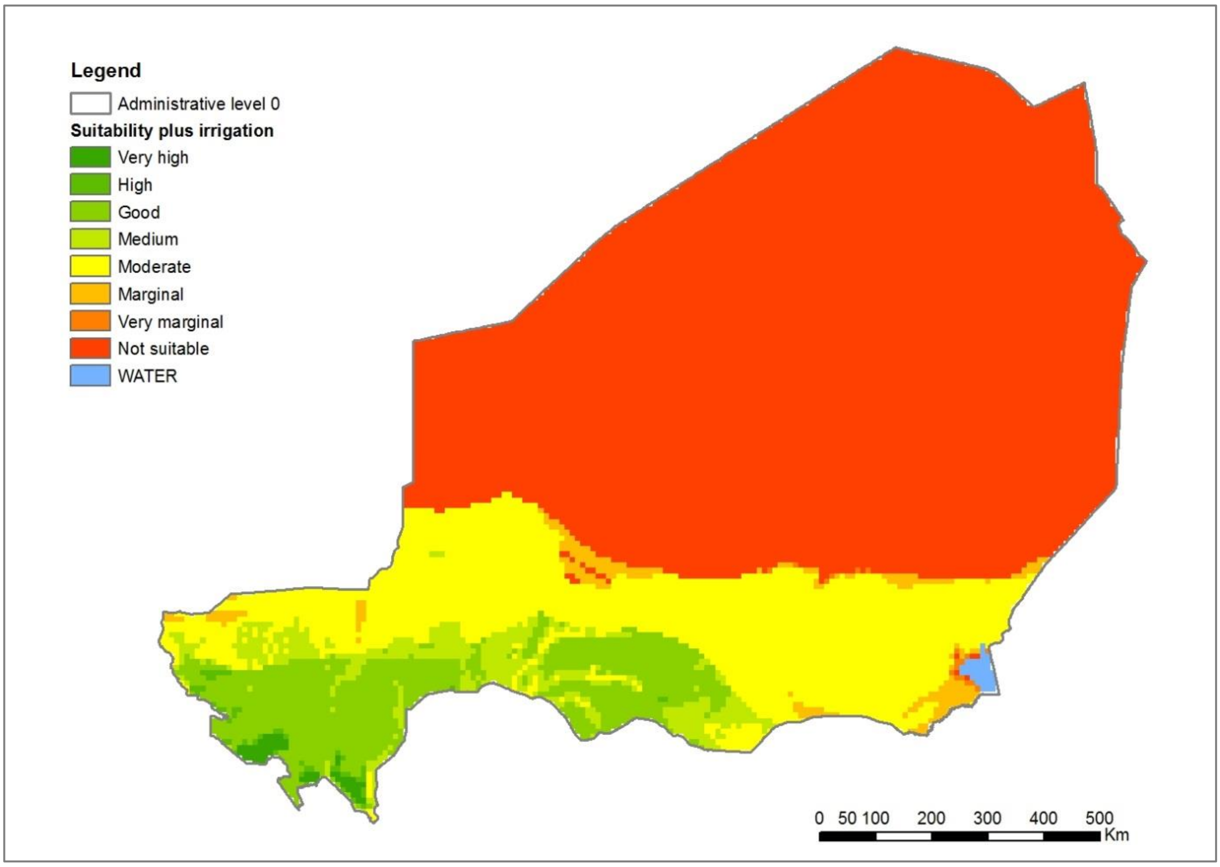

Figure 22 Outcome of the step 2 of the agricultural vulnerability layer processing. It represents suitability values for Niger, as retrieved in step 1, weighted with the irrigation dataset.

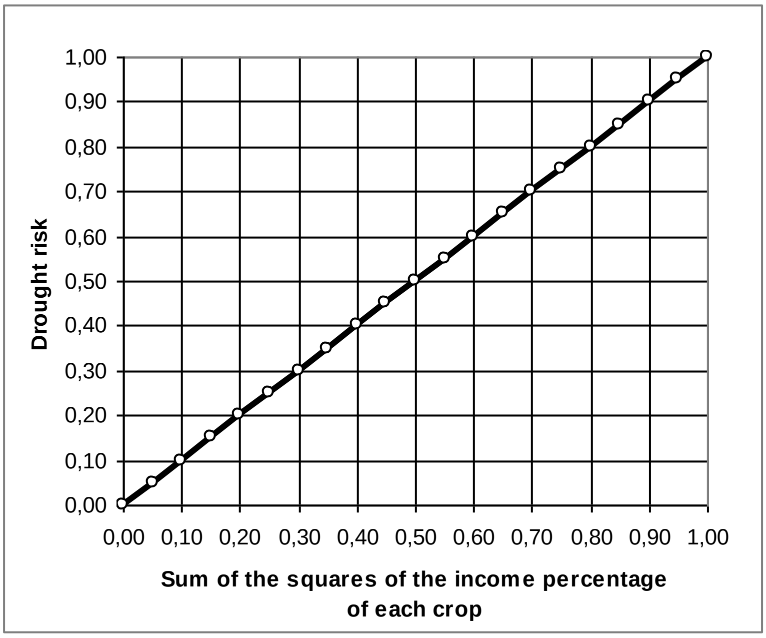

Figure 23 Schematized relation between CDI and drought risk (source Julich, 2006).

Production data were retrieved from FAO CountrySTAT administrative level 1 production database. The index was calculated for the whole set of countries available at FAO CountrySTAT platform by means of a self-developed Matlab procedure (see Annex I - Matlab script for CDI). The CDI values calculated per administrative level 1 were assigned to their respective administrative boundaries (GAUL) in a polygon vector format.

The CDI layer was superimposed to the layer obtained in step 2 (see 4.2.2.2): the pixel of the latter were augmented by a class of vulnerability where the CDI value was bigger than 0,5 unit, given the fact that the CDI is expressed in values that are inversely proportional to the variety of cultivated crops.

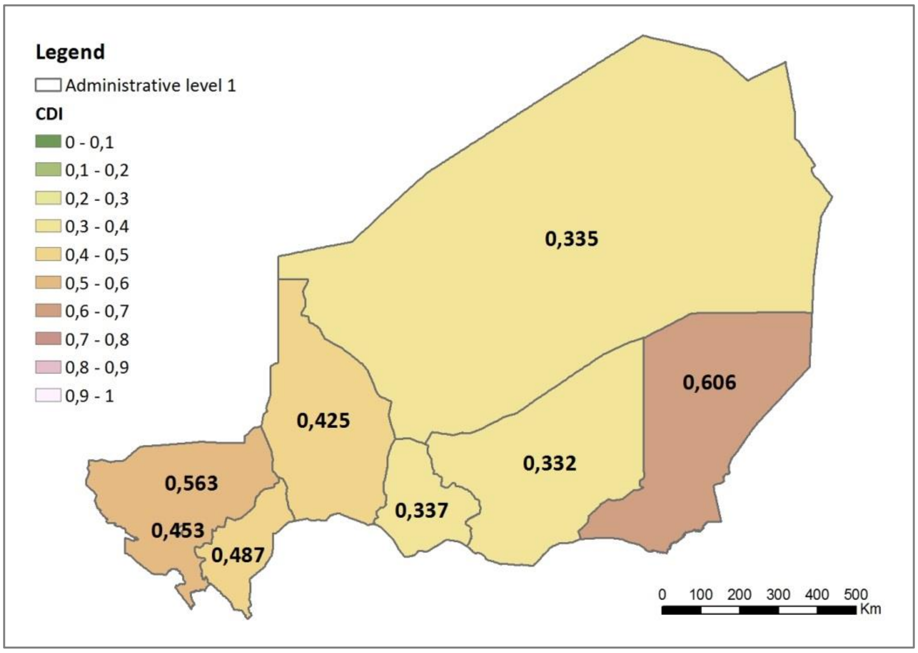

Figure 24 Crop Diversity Index calculated for the Administrative boundaries level I of Niger, represented here in polygon format.

4.2.3 Risk surface

Each risk monitoring system has its own unit to which the alert is attached. On the basis of the procedure with which the hazard or the risk is monitored, the alert is then calculated or aggregated according to specific units. In the present case it has been decided to define specific risk units that are shaped on the basis of various assumptions and models (e.g. poverty distribution and mapping). The objective was to create units that represent people's strategy to sell and buy staple foods. In this way the hazard that hits a particular unit is departed on a homogeneous surface in which the potential impacts could occur.

Three alternative risk surfaces were then created as follows. In the first case an accessibility term was considered; this takes into account both physical distance and travel times (see 4.2.3.1) to identified food source location (i.e. markets or settlements, see 4.2.3.2). In the second case, a food source specific characteristic was used to model the people attraction exerted by the different sources type considered (see 4.2.3.3). In the third case, traditional market flows of goods were enclosed in the model to better represent market catchments (see 4.2.3.3).

In the following paragraphs the models and assumptions applied in order to shape the three types of risk surfaces are described in details.

4.2.3.1 Accessibility – Risk surface I

The term *accessibility* refers to the distance to a location of interest and the ease with which this location can be reached (Goodall, 1987). In the presented vulnerability model the factor that is here introduced, through the use of a risk surface calculated with an accessibility model, has an environmental nature as well as a social one; in fact it has been proven that better access to population and markets centers can lead to diversification of rural economies and contribute positively to the wellbeing of populations. Despite the fact that the important linkages between market access and poverty (e.g. food availability and access) are well known, few studies have tried to pragmatically analyze and model this relationship (F. Pozzi, Robinson, & Nelson, 2010).

The concept of accessibility is borrowed from poverty distribution studies to assume in this work a value inferring the probability, for people living in a determined area, to be able to displace for selling and buying commodities at a specific location.

The considered country was subdivided into market catchment areas calculated on the basis of the easiness to access important markets or most populated cities. These locations were identified through a market survey described in 4.2.3.2. The accessibility was intended as a friction surface that takes into account distance and travel times to markets. When building this type of risk surface the markets were considered equally important. Travel times were calculated as suggested in Pozzi & Robinson, 2008 through the following steps:

I. A speed value is assigned to each type of land cover (retrieved from ESA GlobCover dataset, see Table 2) and each type of road (retrieved from VMAP0, see Table 2) according to the categorization reported in Table 3.
II. Speed values are weighted with slope values (derived by an elevation dataset, i.e. GLOBE DEM, see Table 2), previously categorized into classes of steepness (see Table 4). At this stage a cost surface, in the form of a raster, is obtained. This cost surface is expressed in time needed to cross each cell.
III. A cost allocation calculation, embedded as a system tool in ESRI ArcGis desktop software, is performed; the tool determines, for each cell, the least cost path to reach the nearest source location. A cost distance raster is then produced; each of its cell contains the value, in minutes, needed to reach the identified nearest source location. On the basis of this operation the tool gives also as output a cost allocation raster in which to each cell is assigned the value of the source location identified as the nearest. The country surface is so divided into areas belonging to a specific market. The entire country surface is covered by this classification.

Table 3 Road and land cover classification (source: Pozzi & Robinson, 2008).

Road type	**Average speed (km/h)**
Primary road	60
Secondary road	30
Others	30
Land Cover type	**Average speed (km/h)**
Open or sparse grasslands, croplands, mosaic of forest/croplands or forest/savannah, urban areas	3
Deciduous shrubland or woodland, closed grasslands, tree crops, desert (sandy or stony) and dunes, bare rock	1,5
Lowland forest (deciduous or degraded evergreen), swamp bushland and grassland, salt hardpans	1
Submontane and montane forest	0,6
Closed evergreen lowland forest, swamp forest, mangrove	0,3
Water bodies	-

Table 4 Slope classification (source: Pozzi & Robinson, 2008).

Slope (%)	**Reclassification (%)**
0 - 2	100
2 - 5	80
5 - 8	60
8 - 12	50
12 - 16	40
16 - 32	20
> 32	10

The whole workflow was implemented using the ESRI ArcGis Model Builder, thus allowing reproducing the procedure for other countries, according to their input data availability, simply by changing the model parameters. The developed Accessibility model can be found in the ANNEXES.

Data and datasets used have different spatial resolution and extent; therefore they were superimposed and downscaled or upscaled to the resolution of 300 m, which is the best resolution available among the data considered, in order not to lose the thematic content belonging to the land cover dataset. However the spatial accuracy of the output product is not meant to be 300 m, i.e. higher than that of the input datasets themselves.

4.2.3.2 Market analysis

Market information contributes to food security analysis, and thus to this work, by adding a dynamic aspect to the analysis and improving scenarios development and monitoring. In fact livelihoods are strictly dependent on markets where people sell and buy not only food and agricultural inputs, but also labor and other non-food items. Nonetheless market analysis is crucial for implementing external responses to food insecurity, since it is recognized that market presence can alleviate or aggravate food insecurity (Beekhuis & Laouali, 2007; Sanogo, n.d.).

The presence of markets makes an important contribution to the pillars of food security (i.e. availability, access and use, for more details refer to section 2.5), and this is the reason why it has been decided to include a market analysis in the vulnerability model herein presented. The above-mentioned contributions are listed in the following (FAO, 2008):

- Availability - producers are able to purchase food and inputs for producing food. The movement of food through a country's market network, from surplus to deficit areas and across borders, may help to ensure stable food supplies over time and space. Moreover countries can trade with each other to provide enough food to satisfy population's needs.
- Access - households sell their products (e.g. crops, livestock, and non-agricultural commodities) and their labor in the market to earn income. The price of food in the market determines whether a household's income or resources are sufficient to purchase an adequate amount of quality food.

Moreover an efficient and adequate marketing system is a presumption for agricultural diversification, which guarantees better prices to producers who sell their harvest and the availability of competitively priced produce to consumers (Tracey-White, 1999). For the sake of this work a market survey was conducted in order to properly choose reference markets to include in the analysis. The aim was to identify typical market categories that can be observed in developing countries.

The main broad classification that can be applied to markets refers to the context considered (Tracey-White, 1999), i.e.:

- rural context - primarily concerned with the infrastructure needs of producers for the assembly and marketing of surplus produce to urban areas and export;
- urban context - concerned with the wholesale and retail distribution of food products to consumers within an urban area and with further distribution to other urban areas and for export.

The linkage between rural and urban areas is normally provided by a network of market intermediaries, such as the following list provided by Tracey-White, 1999:

- farmers selling directly in the market (very common in rural markets);
- petty traders and assemblers;
- wholesalers;
- commission agents, sometimes acting as auctioneers, and brokers;
- transporters and transport agents;
- retailers.

The agricultural market network normally includes the following types of market (Tracey-White, 1999):

I. Rural primary markets: where trade is characterized by direct sales of small quantities of produce by producers to village traders and of sales by retailers to rural consumers. Rural markets are normally part of a trade network and are arranged on specific weekdays. They are often found at a central place in a village or district center or beside the access road. In some cases, provincial and district-level markets also serve this function, as well as providing an assembly function (i.e. assembling produce in larger quantities for onward sale to outside buyers).

II. Assembly markets: where great quantities of produce are traded, either by the producers themselves or by traders. These assembly markets (often combined with local rural markets), are normally situated on main highways, or nearby ferries and other local transport nodes. Produce is predominantly bought by traders or collection agents on their own or by urban wholesalers.

III. Wholesale markets: they are located within or near major cities (usually with populations exceeding 0.5 million). These markets may be supplied by purchasing in assembly markets in the rural areas or directly from local produce, either by traders or large farmers. Many wholesale markets incorporate farmers markets where farmers can sell directly to retailers.

IV. Retail markets: where consumers are directly served. They are found in main urban areas. Although primarily retail, they may have some semi-wholesale functions, particularly if they allow farmers to trade. In that case, they can be called farmers markets.

V. Other marketing channels: unconventional markets that often exist, particularly in the case of horticultural produce. These categories include on-farm sales, where collectors purchase the produce (usually under contracts between producers and distributors) and arrange transport to wholesale markets. The extent to which this trade is done primarily depends on the general state of development of the economy and the consumer demands.

The cited market categories are normally applied to different type of commodities (e.g. maize, millet, wheat etc.). In the framework of the present study all the commodities produced were analyzed as a whole and the market categorization is the output of the entire national production market network. A less complex categorization of markets has also been applied in this work considering the aim of simplification; i.e. only assembly, wholesale and retail markets have been considered. These choices are due to the scarcity of market-related data and to the heterogeneity of market data if different countries are considered. Being the final aim to run the proposed model at a global extent, the previous assumptions were then considered effective.

Market supply is the amount of a commodity being offered in a particular market. It can come from local production, private or public stocks, regional or international trade and food aid. Since market supply can be seen in terms of food availability, in the present work the local market supply was considered influencing the food security of a market catchment. However it has to be pointed out that food consumed on the farm is normally not included in the market supply, in this work this term is considered negligible and only the local supply is considered.

The localization of market centers has been retrieved, for the analyzed case studies, from local surveys mainly conducted by international humanitarian organizations. These have been used as is in the case of the accessibility model, while they have been given an importance factor in the case of gravity models (see paragraph 4.2.3.3).

4.2.3.3 Gravity models – Risk surface II

Market areas own an economic sense that does not correspond to other more commonly used territorial or administrative divisions (e.g. towns, provinces, regions or countries). In this paragraph various theories of delineation of trade areas will be presented. These concepts, while not conceived for the purpose of market analysis in developing countries, are considered of interest for this application and promising in the field of market catchment automatic delineation. In particular, the possibility of overlooking periodical field survey data is extremely important in the context of monitoring and early warning systems, especially when applied to developing countries.

Reilly (1931) was the first in tackling the delimitation market problem. Based on the Newtonian law of gravitation, his model is the precursor of the gravity spatial choice models commonly used today. Many studies have later implemented and sharpened his statements, opening an important path in geographical marketing (Applebaum & Cohen, 1961; Christaller, 1933; Fotheringam & O'Kelly, 1989; Huff, 1962; Jones & Mock, 1984; Rust & Donthu, 1995).

Reilly's law of retail gravitation considers both distance and attractiveness of alternative shopping opportunities. The notion that agglomeration tends to increase the attractiveness of stores is key to Reilly's law, i.e. stores located in centers with greater populations draw customers from farther distances than those in less inhabited centers. Based on the Newtonian law of gravitation, Reilly's theory was the first to state that consumers trade off the cost of travel with the attractiveness of alternate purchasing opportunities. This deterministic law states that the proportion of retail trade attracted from intermediate towns by two competing centers is directly proportional to their population and inversely proportional to the square of the distances from those centers to the intermediate towns. The attractiveness of a center is measured by means of two variables: center population (i.e. the mass term), which exerts a positive attraction over consumers, and distance (i.e. the friction term), which discourage consumers from moving. The mass variable can be expressed as the size of the towns in terms of population or as sales surface (e.g. square meters) (Chasco Yrigoyen & Vicéns Otero, 1998). However as Fotheringam and O'Kelly (1989) pointed out, the gravitation model is based on the assumption that though the variables that explain the spatial choice of an individual tend to be very similar to those that explain the spatial choices of a large number of individuals, on the individual level, spatial choice is evidently more behavioral.

A step forward in the spatial choice model development was made in 1963 by Huff, who was the first to propose a spatial-interaction model for estimating retail trade areas. His theory takes into account the fact that when consumers have various shopping opportunities, they would probably visit several different stores rather than restrict their choice to a single outlet.

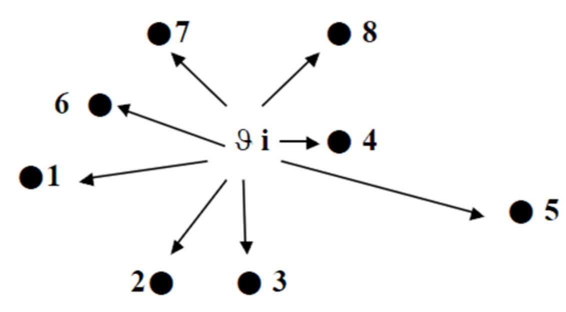

Figure 25 The spatial choice problem (source: Chasco Yrigoyen & Vicéns Otero, n.d.).

This assumption lead to the consequence that each store within the analyzed geographic area has some chance of being patronized. Therefore Huff introduced a probabilistic approach for the definition of trade areas, i.e. each store has a certain probability of being chosen by consumers. This probability increases with a so called attractiveness factor of the outlet and decreases with the square of the distance. Huff's probability function is provided in equation [5]:

$$P_{ij} = \frac{U_{ij}}{\sum_{k=1}^{j} U_{ik}} = \frac{S_j^{\alpha} D_{ij}^{\beta}}{\sum_{k=1}^{j} S_k^{\alpha} D_{ik}^{\beta}} \qquad [5]$$

where
i: is the location of the consumer;
P_{ij}: probability of consumer at i visiting store j (or town j);
J: is the set of competing stores (or towns) in the region;
U_{ij}: utility of store (or town) j for individual at i;
S_j : size of outlet j (or set of outlets of town j);
D_{ij}: distance between consumer at i and store (or town) j;
α, β: sensibility parameters (α = 1 and β = -2).

Huff introduced in his formula [5] the concept of utility (U) of a store, which depends on its size (S) and distance (D) from consumer location. To determine the probability of a consumer visiting a particular store (P_{ij}), Huff used Luce's axiom (1959), which postulates that this probability equals the ratio of the utility of the considered store (U_{ij}) to the sum of utilities of all the stores in the geographic area analyzed.

In order to adapt Huff's law to the present study several considerations had to be made:

- it is unlikely that people's strategy to buy and sell commodities in developing countries is submitted to the same assumptions made for retail trade area definition (e.g. possibility to move across relatively long distances);

- the mere size of markets, whether the data is available, is possibly a variable that does not represent correctly their attractiveness for the consumers;
- when a whole country surface has to be analyzed, the Euclidean distance may not be a realistic way to measure distances.

The above-mentioned issues were addressed as follows:

- the size of the store (S) was substituted with an importance factor related to the type of market; i.e. markets were assigned importance values of 3, 2 or 1 when belonging to the categories Wholesale, Assembly and Retail, respectively;
- the Euclidean distance (D) was replaced by the distance calculated with the accessibility model (see paragraph 4.2.3.1) in order to take into account physical hindrances and therefore rather realistic travel times.

It should be noted that the use of different variables in place of the size of the store and the use of a sort of weighted distances was previously suggested by other researchers (Chasco Yrigoyen & Vicéns Otero, 1998).

To calculate the modified Huff gravity model a three step workflow has been implemented in a GIS environment. The Model Builder, embedded in ESRI ArcGIS desktop software, was used in order to be able to reproduce the workflow when needed (see the ANNEXES for the Huff tool explanation).

In the first step the accessibility distance, expressed as travel times in minutes, is calculated for the whole country surface for one market at a time. The accessibility distance is multiplied for the importance factor, previously assigned to each market. A number of utility raster equal to the number of markets is produced. In the second step, the ratio of the utility per market to the sum of utilities is calculated per each market at a time. The result of this process is a set of raster, each of that representing the probability for a consumer to visit the market considered. Therefore each pixel of one of these rasters own a value of probability related to a particular market, which depends not only on the distance to and importance of that market but also on the utility of all the other markets included in the analysis. The third step compares the probability rasters obtained from the previous step and returns as outputs: (i) the maximum probability value for each pixel and (ii) an identifier of the raster (i.e. a specific market) to which this maximum value belongs.

A representation of the whole workflow applied to implement the Huff gravity model is given in Figure 26.

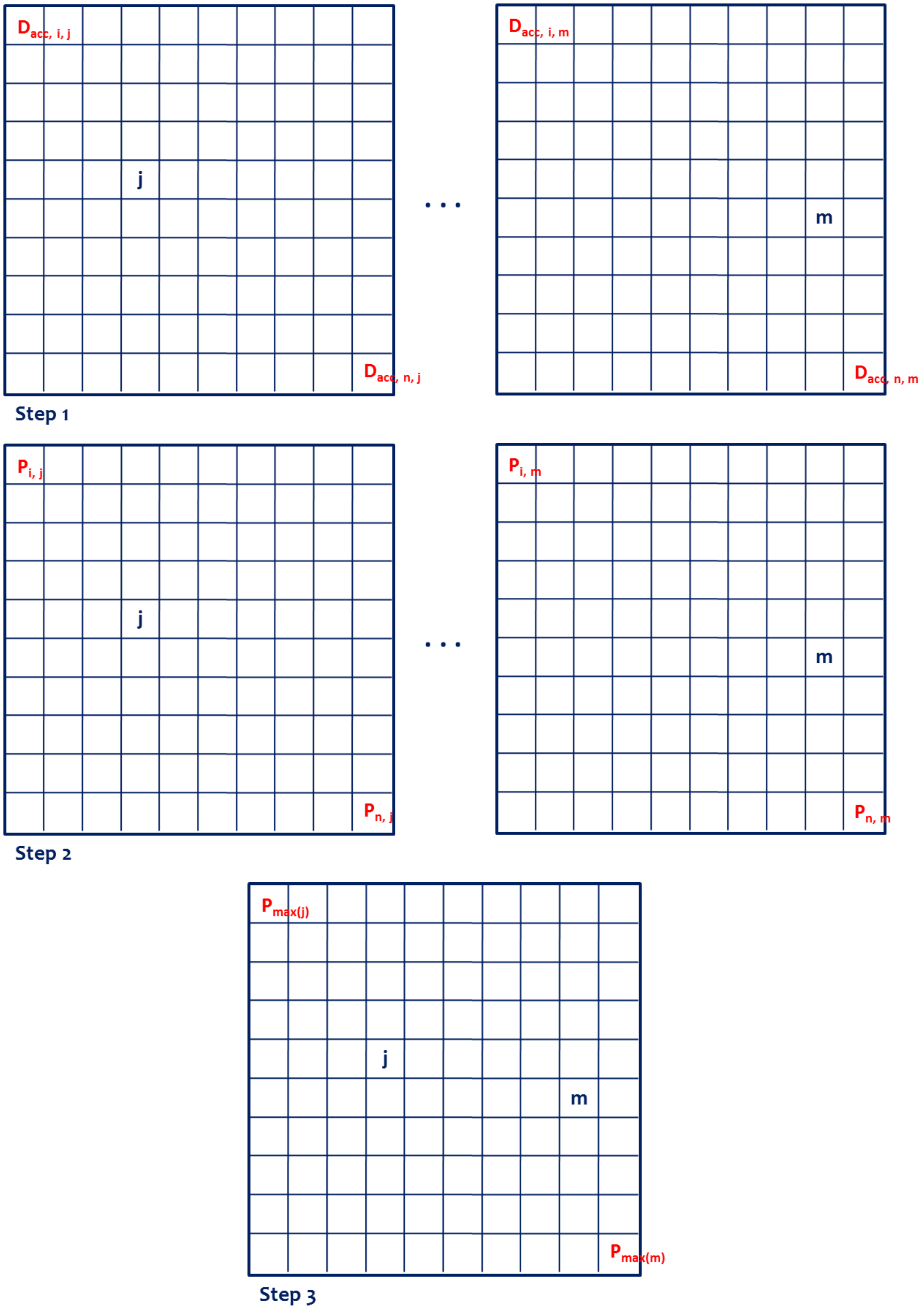

Figure 26 Schematization of the building of risk surface implementing the gravity model. D_{acc} in step 1 is the accessibility distance calculated for each cell i to reach market j or m. This value is multiplied per the importance factor. The probability of a consumer to go to market j or m ($P_{i,j}$; $P_{i,m}$) is calculated in step 2. Step 3 retrieves the highest probability for each cell and stores it in a single raster.

4.2.3.4 Gravity models with market flows – Risk surface III

The risk surface of third type was built by using the gravity model output (see 4.2.3.3) and by adding data related to known flow of staple food from a market to another. In fact it has been proven that, especially in developing countries, traditionally production surplus areas supply those areas that cannot satisfy their population food need with local production, this happening even during average production years.

In order to consider these trades among markets, a good knowledge of the functioning of the market network is needed. In the present work these information were retrieved locally, thanks to WFP local offices, only in the case of Niger, therefore for this one and only case the third risk surface was produced and experimented.

The practical case being exposed in section 4.3.1.2, only the main rationale behind the procedure implemented to obtain the third risk surface is described here: by considering the units of risk surface ii, and after the analysis of market flows, it has been decided to distribute the alerts that relapse on traditionally food surplus areas over the areas that are normally supplied by the latter. In the same way when food deficit areas are alerted, the surplus areas where the food come from are screened and if none or minimal alert is found, then the deficit area alert are diminished.

It must be pointed out that the risk surface iii is not spatially different from the second one, whereas in the third one the relations among markets are taken into account in the phase of alert spreading over risk surface units.

4.2.4 Weighted hazard

This paragraph explains the procedure implemented in order to produce the weighted hazard per pixel. The output herein produced is an intermediate output functional to the final alert. As reported in paragraph 4.2, the hazard produced by ITHACA vegetation monitoring system has to be superimposed and weighted with the Agricultural Vulnerability layer.

The considered hazard values (i.e. Seasonal Small Integral Percent Deviation) are expressed in percentage of deviation with respect to the average value of the parameter calculated over the whole time series, and can vary in the range +400 ÷ -400. Only the negative values are considered in this study because they represent the anomalies that can cause the drought impacts. On the other hand Agricultural vulnerability values are expressed by classes of integer varying from 0 to 8, the ascending order accounting for increasing vulnerability.

Firstly the hazard raster is clipped with the crop areas in order to consider only the alerts that are meaningful because impacting a valuable land; then each retained hazard pixel is multiplied by the agricultural vulnerability value. The resulting map is expressed in the same units as the hazard; an example is given in Figure 27.

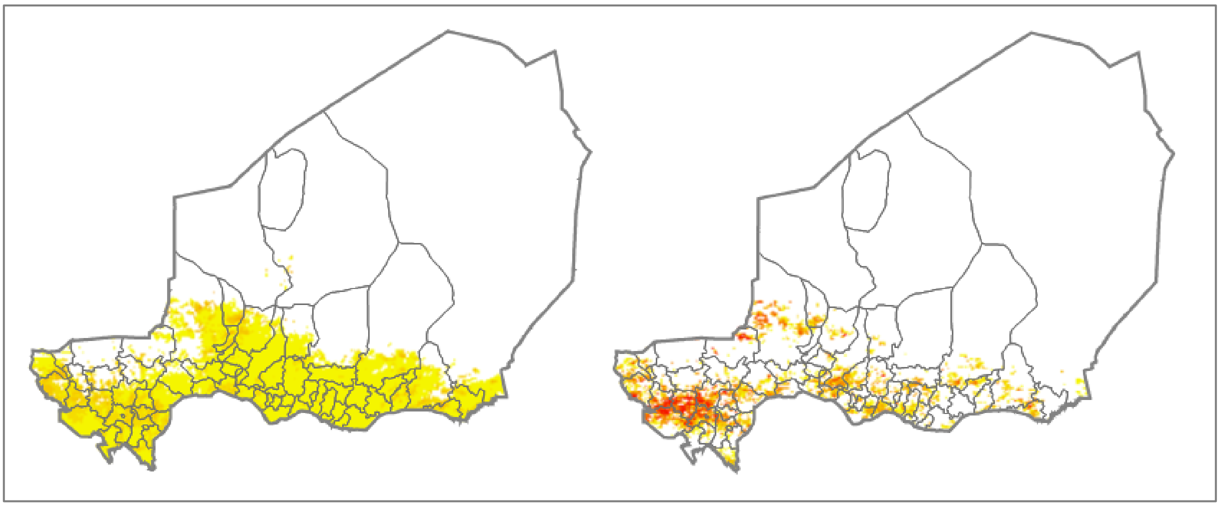

Figure 27 An example for Niger of hazard per pixel is reported on the left, weighted hazard per pixel is shown on the right.

The procedure is implemented in ESRI ArcGIS Model Builder and is reported in the Final Alert Model detailed explanation provided in the ANNEXES.

4.2.5 Final alert maps

The production of the final alert is reported in the current paragraph. In this phase the weighted hazards produced in the previous steps are treated to be aggregated per risk surface unit.

The ratio of the number of alerted pixel to the total number of crop pixel is calculated per each risk surface unit; where this ratio surpasses a threshold value of 20% the corresponding risk surface unit is alerted. The alert value that is associated with each risk surface unit is the mean value of the alerted pixel multiplied by the previously calculated ratio. The latter gives an account for the relevance of the considered anomalies on the basis of the portion of the impacted cropland.

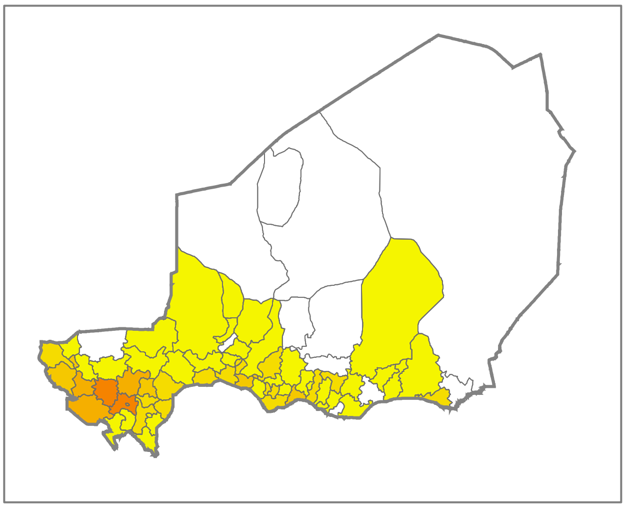

Figure 28 Example for Niger of Final Alert given per Risk Surface units (alert values increases from light yellow to dark orange) obtained from the weighted hazard represented in Figure 27 (on the right).

This step of the procedure was implemented in ESRI ArcGIS Model Builder too, and is reported in the Final Alert Model detailed explanation provided in ANNEXES. An example of final alert aggregated per Risk Surface units is provided in Figure 28.

4.3 Case studies

The effectiveness of the inclusion of the proposed vulnerability model into the ITHACA EWS was tested over a selection of country having experienced recurrent drought. The vulnerability model was applied to the hazard, i.e. one of the products of the ITHACA EWS, for the time series 2006-2013 thus generating one final alert per year and per country. For each of the case studies the produced final alerts were compared with food security historical data. One case study is located in Southern Africa (i.e. Mozambique) and another one in Western Africa (i.e. Niger). Those two countries share with other developing countries the issues of scarce data availability and difficult data remote access when food security data are considered. Especially in those cases the usefulness of a EWS for drought is undeniable, this was one of the reasons for those countries to be selected. In particular for what concern Niger a field mission, performed during October 2013, allowed to retrieve specific data linked to food security based on periodic field surveys (see 4.4.2) that made possible the development of a quantitative evaluation of the final alert produced.

An accounts of the characteristics of the two case studies, along with intermediate outputs of model application, is provided in the following paragraphs.

4.3.1 Niger

Niger is a landlocked country located in the Sahara–Sahel belt. The Country is least-developed, low-income, food-deficit and ranks last on the 2013 Human Development. It has a population of over 16 million: life expectancy at birth is 55 years, the fertility rate is among the highest in the world (7.6 births per woman) and the maternal mortality ratio is 590 per 100,000 births.[17]

Only the half of Niger total area (over 1 million km^2) is habitable due to adverse climatic and soil conditions. Niger has a mainly dry climate with considerable temperature variations. Yearly potential evaporation is 2 to 4 m, while rainfall reaches 800 mm and falls to below 100 mm over almost half of the country. The rainfall pattern is Saharan in the north where it practically never rains, and Sudano Sahelian in the south, where an average of 600 mm of rain falls during approximately four months (from June to September). Rainfall varies, however, from one region to another and its distribution is very erratic (Geesing & Djibo, 2006). Temperatures can exceed 40 degrees Celsius during the dry season, from March to June, while from November to February, they drop considerably (Bernus, Hamidou, & Laclavère, 1980).

A very small percentage of the country is arable (Figure 29). Agriculture is practiced mainly in the south, where millet and sorghum are traditionally grown but maize, sugar

[17] http://www.wfp.org/countries/niger/overview

cane and sweet potato can also be found. Vegetables and fruit trees are growing in the depression of ancient rivers whereas rice is cultivated mainly along the Niger river (Geesing & Djibo, 2006). Although livestock keeping is mainly limited to the northern Niger, the share of cultivated land competes increasingly with breeding (Figure 30). In Sahelian countries in general, land and water resources are subjected to an overwhelming pressure due to population growth and a considerable decrease in rainfall rates (Collinet & Valentin, 1984; Roose, 1977). In particular in Niger clearing and wood-exploitation reduces significantly the original vegetation: just for the capital city Niamey, more than 11,000 tons of firewood are needed per year (Geesing & Djibo, 2006).

The economy of Niger is mainly funded on subsistence farming and stock-rearing, that contributes 40% to the total GDP. Moreover the vast majority of the labour force is employed in the agriculture and livestock breeding sectors. The agricultural yearly production is around 3 million tons of cereals. Cowpeas, cotton and groundnuts are mainly cultivated for export. Millet, sorghum, cassava, pulses, rice, sugar cane and vegetables are grown for local consumption. Fishing is conducted in Lake Chad and in the Niger river, and the catch is consumed or exported locally. Industry is very limited even though Niger subsoil is very rich in important minerals (e.g. tin, gold, uranium) (Geesing & Djibo, 2006).

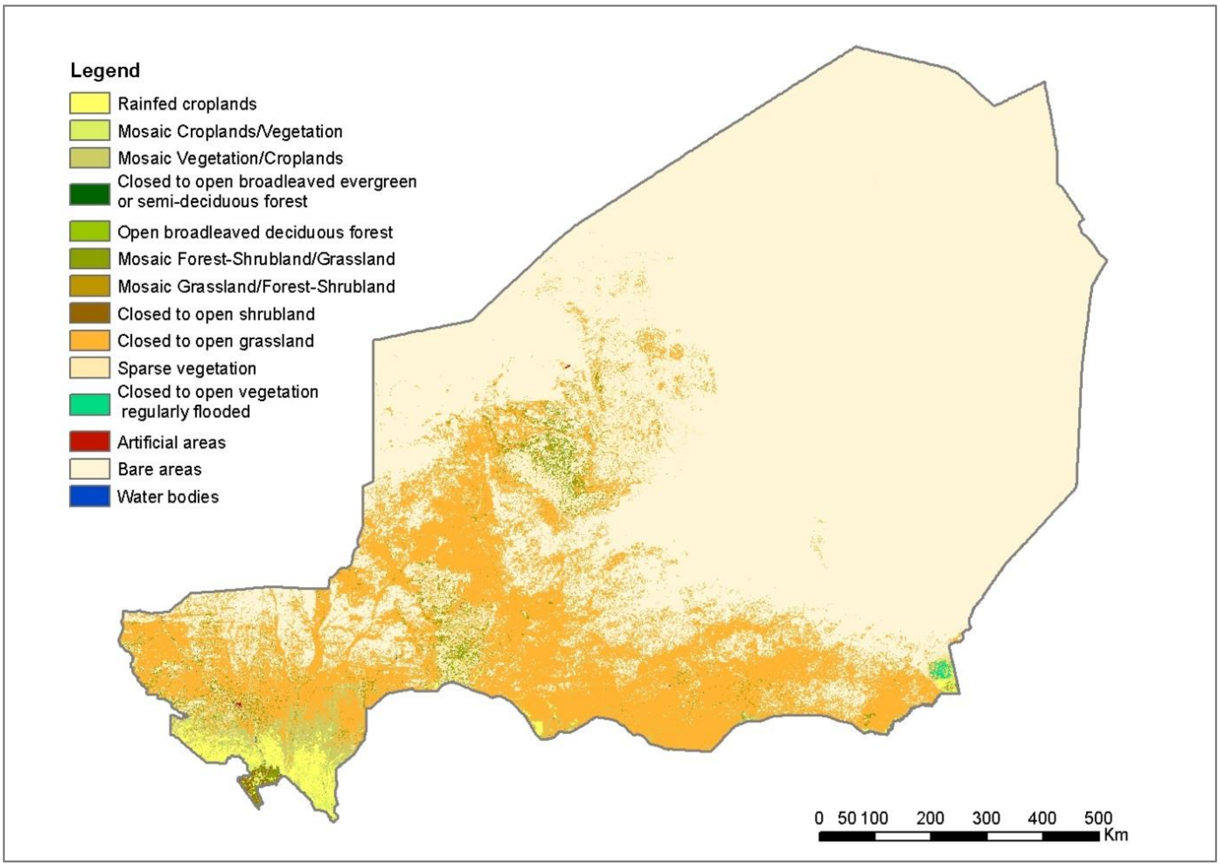

Figure 29 Niger land cover (source: ESAGlobCover, 300 m resolution, © ESA 2010 and UCLouvain, © ESA / ESA GlobCover Project).

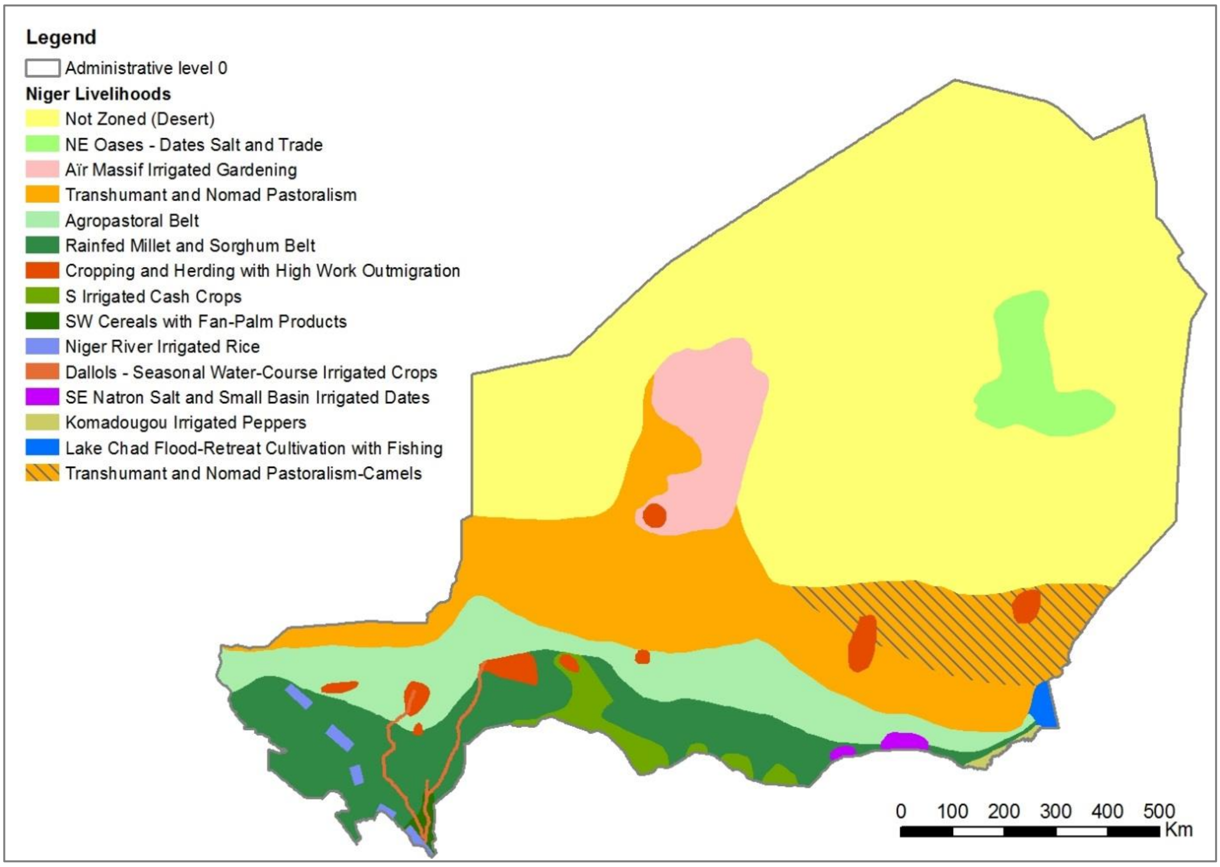

Figure 30 Niger livelihoods (source: Fews Net website http://www.fews.net/ accessed on January 2011).

The delineated country overall scenario is thus constituted of over-reliance on subsistence rain-fed agriculture and animal husbandry, widespread poverty, limited infrastructure, low levels of education, and limited effective coverage of basic services, aggravated by high population growth, high levels of indebtedness, and recurrent crises. These conditions have weakened the resilience of the most vulnerable people. World Food Programme statistics estimates that 2.5 million people in Niger are chronically food-insecure and unable to meet their basic food requirements even during years of average agricultural production. By consequence, during periods of constrained access to food, millions more can quickly fall into acute transitory food insecurity [18].

4.3.1.1 Sahel and Niger Early Warning Systems

During the 20th century the Sahel region have passed through several extensive drought events, among which the major droughts of 1973 and 1984, and consequent food crises (Glantz, 1987). The CRED-EM database registers for its whole time span (1900-2013) more than 70 million affected by drought in Western Africa, of which nearly the half was affected in the last 20 years. Niger is the most affected country of the region per number of occurrences and per people affected (see Table 5).

[18] http://www.wfp.org/countries/niger/overview

Table 5 Drought occurrences and impacts in Western Africa, 1900-2013 (source EM-DAT: The OFDA/CRED International Disaster Database – www.emdat.be – Université Catholique de Louvain – Brussels – Belgium.).

Country	Droughtevents	Killed	Affected
Benin	2	0	2 215 000
Burkina Faso	12	0	8 413 290
Cape Verde Is	10	85 000	40 000
Cote d'Ivoire	1	0	0
Gambia The	8	0	1 258 000
Ghana	3	0	12 512 000
Guinea	2	12	0
Guinea Bissau	6	0	132 000
Liberia	1	0	0
Mali	11	0	6 927 000
Mauritania	12	0	7 398 907
Niger	13	85 000	23 655 058
Nigeria	1	0	3 000 000
Senegal	9	0	8 399 000
Togo	3	0	550 000
Total	**94**	**170 012**	**74 500 255**

For the abovementioned reasons, West African and Sahelian states, together with their inter-governmental organizations, have invested in the formulation and implementation of food and nutritional security policies since the early 2000$_s$. This has resulted in the adoption of several policy and operational frameworks:

- the CILSS Strategic Framework for Food Security (CSSA);
- the Agricultural Policy of the West African Economic and Monetary Union (PAU);
- the Common Agricultural Policy of the Economic Community of West African states (ECOWAP);
- the Policy on Disaster Risk Reduction;
- the Labour and Employment Policy; and
- the Humanitarian Policy.

These strategies converge on the following priority areas of food and nutritional security: the search for sustainable structural solutions; the implementation of food and nutritional crisis prevention tools; and the preparation of early- warning responses. These endeavours have also led to a regional agenda for food and nutritional security that includes various information, vulnerability analysis, monitoring and early- warning systems. The pillars of these information systems are:

- the Regional System for the Prevention and Management of Food Crises (PREGEC), including the Cadre harmonisé (CH) for the identification and analysis of at-risk zones and vulnerable populations, facilitated by CILSS;
- the UEMOA Regional Agricultural Information System (SIAR);

- the ECOWAS Agricultural Information System (ECOAGRIS), serving as the umbrella-platform for existing agricultural information systems;
- the Observatory of agro-forestry- pastoral farms as well as the early- warning mechanisms of producers' organizations (POs), led by the West African Network of Farmers' and Agricultural Producers' Organisations (ROPPA), the Billital Maroobe Network (RBM) and the Association for the Promotion of Livestock in the Sahel and Savannah (APESS).

The regional agenda counts also the Charter for Food Crisis Prevention and Management, an assessment tool aimed at improving the effectiveness of food and nutritional strategies and policies. Among the advisory and decision-making governance bodies and networks the Food Crisis Prevention Network (RPCA) has to be cited for its preeminent role in the Sahel region (SWAC/OECD, 2013).

At the same time country governments of the region themselves have developed national early warning systems, integrated to different extents with regional systems.

The government of Niger, in particular, started to develop in 1989 an ensemble of early warning tools constituting, as a whole, the national system for prevention and management of disasters and food crises (Dispositif National de Prévention et de Gestion des catastrophes et Crises Alimentaires, DNPGCCA). An overview of system components and its connections is given in Figure 31. This apparatus counts a general secretariat (Sécretariat Permanent, SP), that is a mechanism of consultation and fund mobilization, an Information System, an Early Warning System (Système d'Alerte Précoce, SAP) and an operational agency (Cellule Crises Alimentaires, CCA) (Cabinet du Premier Ministre du Niger - DNPGCCA, 2013).

Moreover a coordination unit of the Early Warning System (Cellule de Coordination du Système d'Alerte Précoce, CC/SAP) is in charge of the food security data gathering. This unit relies on the following specific data collecting and analysis units:

- Information system of the agricultural market (Système d'Information sur les Marchés Agricoles, SIMA);
- Information system of the pastoral market (Système d'Information sur les Marchés à bétail, SIMb);
- Harvest forecasting and estimation (Enquête Prévision et Estimation des Récoltes, EPER);
- Multidisciplinary working group (groupe de travail interdisciplinaire, GTI);
- Specific working groups (groups sectoriels, GTP);
- Regional and sub-regional committees in charge of the prevention and management of food crises (Comités régionaux et sous-régionaux chargés de la prévention et de la gestion des crises alimentaires, CR/PGCA et CSR/PGCA).

At the administrative level 3 (i.e. municipalities) a vulnerability observatory (Observatoire du Suivi de la Vulnerabilité) coordinates the community-based monitoring system (Système Communautaire d'Alerte Précoce et de Réponse aux Urgences, SCAP-RU).

The SCAP-RU is a system that aims at improving the capacities and responsibilities of base communities in the phases of emergency preparedness and response. In particular, emergencies targeted by the community-based system are those that can affect the normal lifestyle of households.

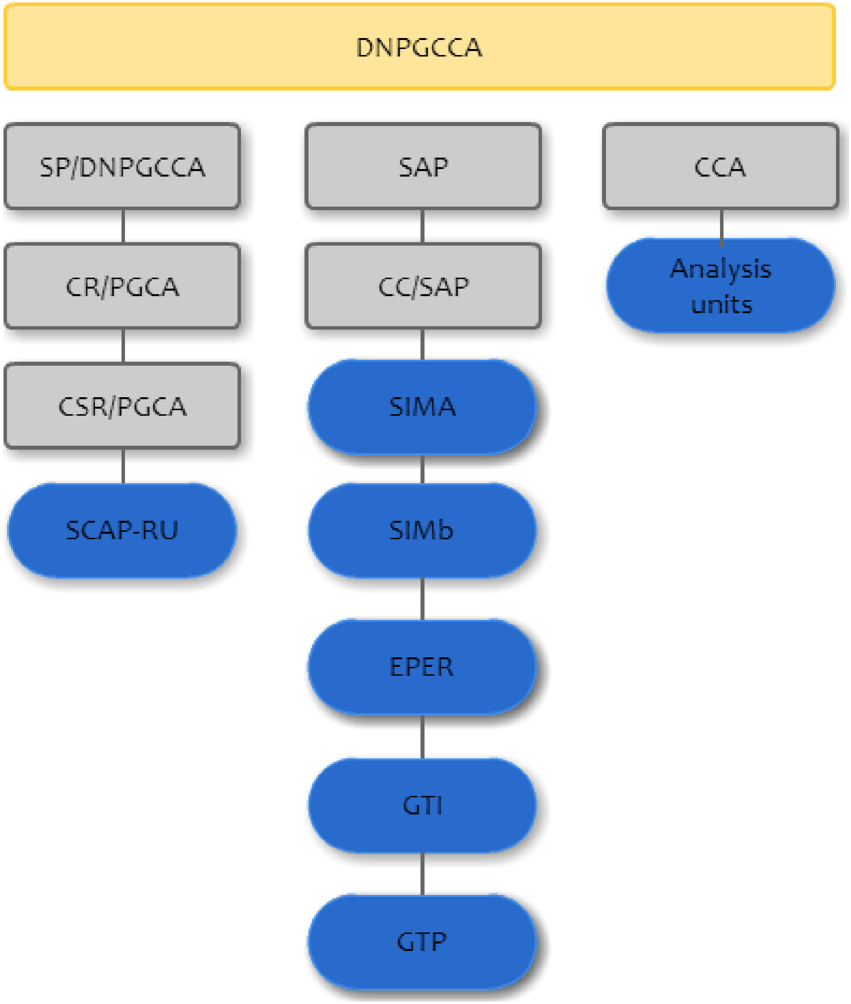

Figure 31 Synthesis of the early warning system coordination and reporting structure (source: République du Niger presentation "Country early response contingency planning against drought" given in Paris on 18/09/2012 for the Contingency Planning Peer Review Meeting).

Activities promoted by the SCAP-RU, which influence the level of effective response when a crisis occurs, are:

I. Organize the chain of emergency information, from production to access to the profit of local communities (i.e. awareness building about the importance and the need of this kind of warning system; identifying indicators, alert levels and type of response; gathering and analyzing data; correctly use emergency information in a way to shape the response and minimizing the impacts).
II. Determine a range of actions to be implemented depending on the type of hazard and on the alert level.
III. Identify and establish both institutional and informal community alliances at different geographic level.
IV. Build capacities at the community level for a prompt response in case of a crisis.

V. Create and maintain a confidence level between the institutional warning system (DNPGCCA) and the community one.

The complex Niger EWS, illustrated so far, is relatively new and continuously improved year after year. In the actual situation zones in which the tasks of the respective institutions are overlapped can be noticed, and a general lack of coordination of the information chain as well. Nonetheless various UN programs and projects, as well as international NGOs, developed their own monitoring and EW Systems that in some cases still coexist with the governmental ones and in other cases contribute to it. As a result various operative agencies are still using their own produced data, thus engendering duplicate efforts and possibly controversial outputs.

In the described context it could be crucial to automatically and univocally determine: (i) hazard levels that trigger drought crisis, (ii) spatial links between zones impacted by the hazard and zones impacted by the effects. Tracking success and fails of existing EWS would also be of help for better calibrating the systems. A transparent and effective methodology would be helpful for operative agencies and their donors.

The proposed vulnerability model is run with available Niger data and, after being applied to ITHACA EWS product, is validated with locally retrieved validation data (see 4.4.2) and with regional food security outlooks produced by Fews Net (see 4.4.1).

4.3.1.2 Applied model, input and intermediate results

The conceptual model described in 4.2 was adapted to Niger case study; details are given in the following.

Firstly the **agricultural vulnerability surface** was obtained as reported in 4.2.2. In order to do so the most produced crops per administrative level 1 (given in Figure 32) were retrieved from the FAO CountryStat database (local statistics). The Crop Diversity Index was calculated using the same base data. The results are summarized in Table 6.

Table 6 Most produced crops and CDI given per Administrative level 1 of Niger.

Administrative level 1	Main Crop	CDI
AGADEZ	MAIZE	0,34
DIFFA	MILLET	0,61
DOSSO	MILLET	0,49
MARADI	MILLET	0,34
TAHOUA	MILLET	0,42
TILLABERI	MILLET	0,56
ZINDER	MILLET	0,33
NIAMEY (municipality)	MILLET	0,45

The most produced crop for all regions, except Agadez, is millet as could be expected. In fact this corn is widely consumed as staple food in Niger partly due to the fact that it is adapted to its semi-arid climate. The phenomenon is also explicable considering that farmers largely produce for their own consumption.

Given the main cultivated crop per Administrative level 1, the correspondent Crop Suitability was retrieved from the GAEZ database (reported in Figure 33 a).

An intrinsic agricultural vulnerability appears clear if one analyzes the Crop Suitability for the country as a whole; the presence of the desert in the northern part of the country is reflected in an almost negligible suitability or a moderate one moving towards south. Only small portions in the southern part of the country are classified with good to very high suitability.

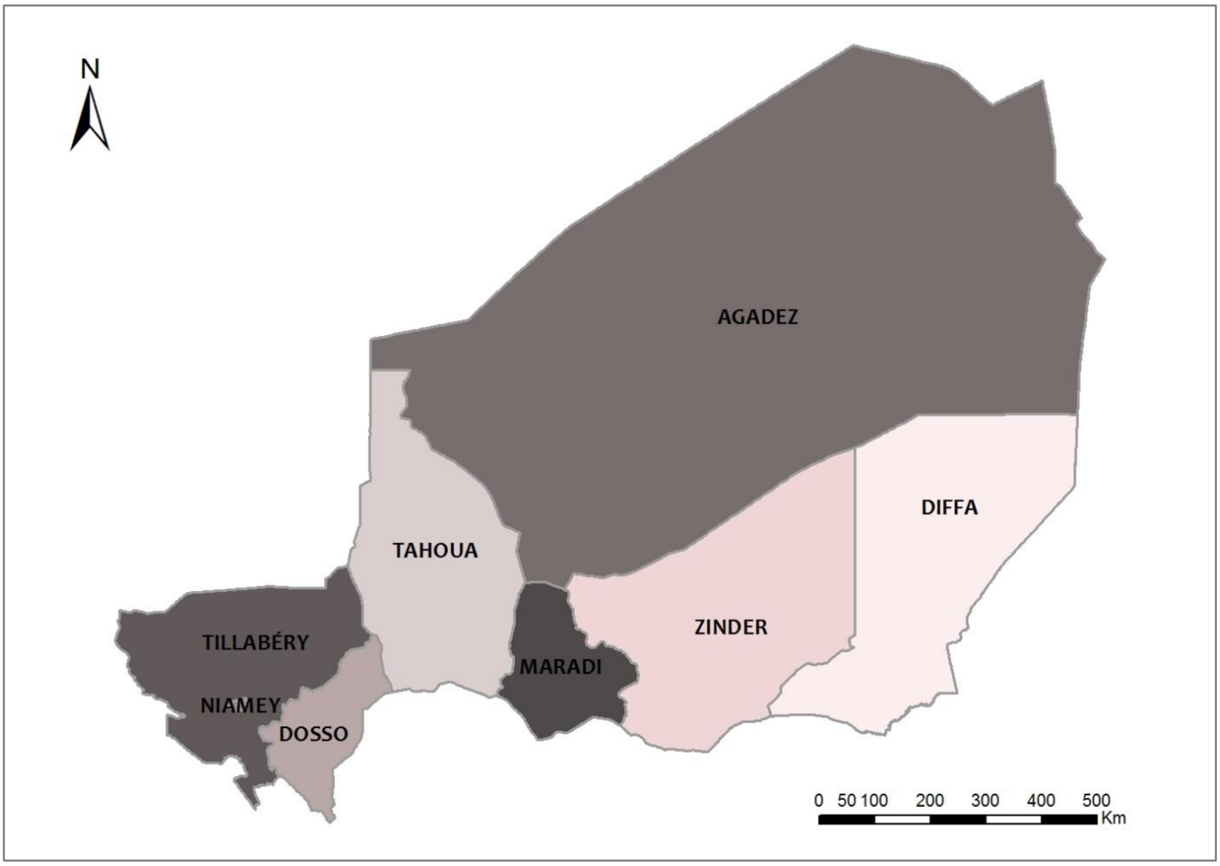

Figure 32 Niger administrative level 1 subdivision (source: GAUL, 2008).

The CDI was calculated on the basis of the CountryStat production per administrative level 1 (see Figure 33 b). CDI values were used in the Agricultural Vulnerability model (for more details see Annex III - Developed tools) to decrease the agricultural vulnerability by a class where the CDI value was smaller than 0.5 (i.e. CDI value is inversely proportional to the variety of crops cultivated). The result of this step is reported in Figure 33 c.

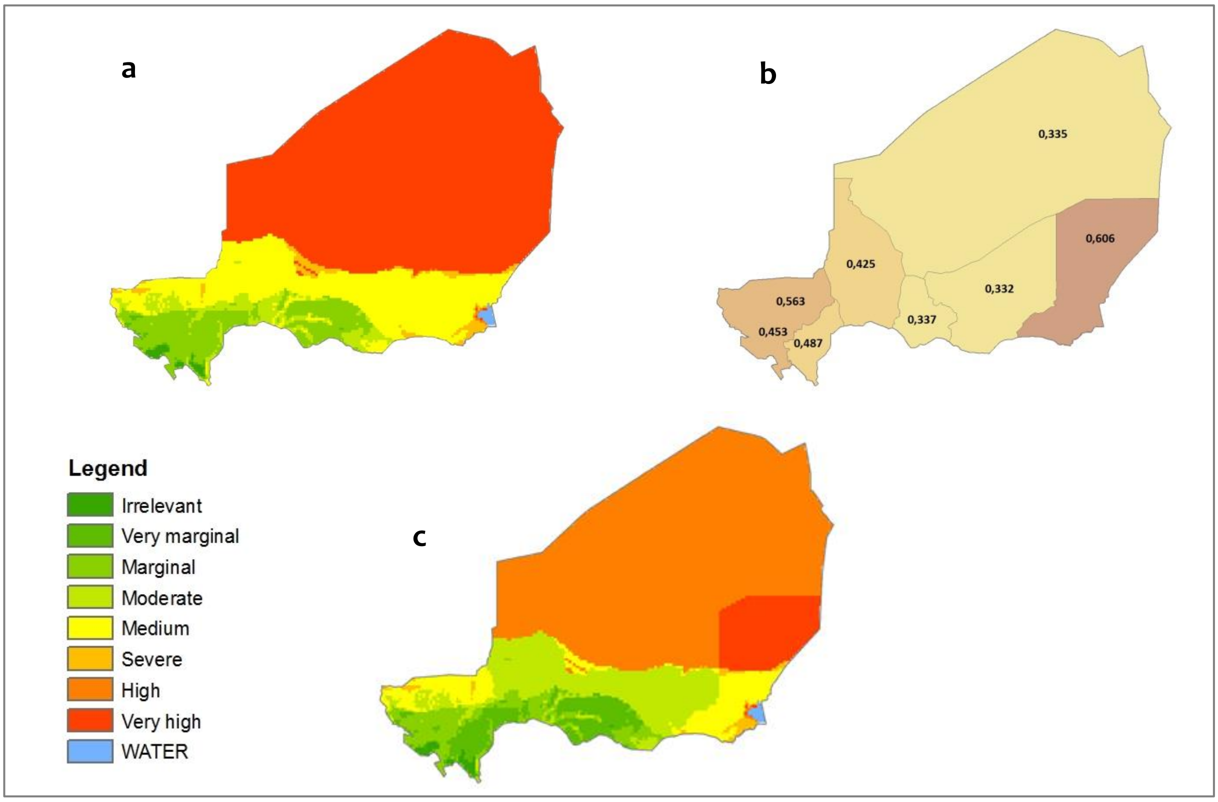

Figure 33 Crop suitability for Niger is reported in a, while the CDI calculated per administrative level I is reported in b. The result, i.e. the Agricultural Vulnerability, is shown in c.

In parallel the **risk surface** for the considered Country was calculated in three different ways, alternatively considering:

i. The only accessibility model applied to the whole set of markets (called hereafter **risk surface i**);
ii. A gravity model applied after a market classification depending on their importance (called hereafter **risk surface ii**);
iii. A gravity model integrated with traditional flux of goods among markets (called hereafter **risk surface iii**).

The physical accessibility was calculated as explained in section 4.2.3.1 by using VMAP0 infrastructure linear features (i.e. roads), ESA GlobCover (i.e. land cover) and GLOBE (i.e. DEM) for Niger. Among the intermediate outputs of the accessibility model are a friction raster, showing the time needed to cross each cell calculated according to the land cover and infrastructure types as well as land steepness (see Figure 34), and a cost-distance raster, containing the values expressed in time for each of the raster cell needed to reach the nearest market, that serves as base for all the three risk surface options. In the **risk surface i** an area allocation per market is defined on the basis of the cost-distance values. In the **risk surface ii** and **iii** the cost-distance values calculated for each market one at a time, replace the Euclidean distance in the original gravity model formula (for more details see paragraph 4.2.3.3). The cost-distance output for Niger is reported in Figure 35.

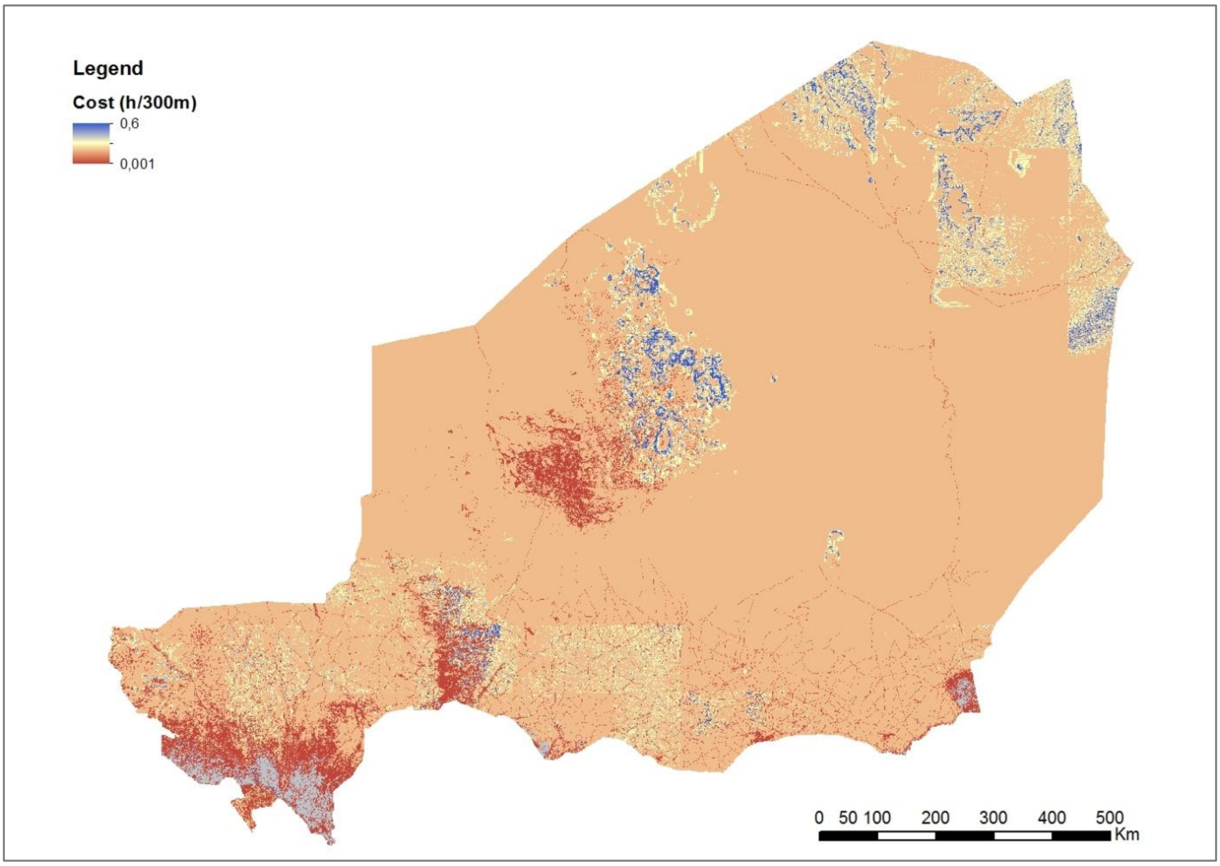

Figure 34 Cost raster (i.e. friction surface) that represents, for each cell, the time needed to cross the cell size. Lower values in correspondence of roads are clearly visible (in red) in the map.

In all cases the market dataset (shown in Figure 38) was obtained from the combination of three sources, i.e. the global market locations made available by the VAM-WFP headquarter; the national market database furnished by VAM-WFP Niger local staff; the national market database provided by the operators of the SIMA. The first two sources account only for the geographic coordinates and name of the markets, providing a list of 74 national markets. The third source is a comprehensive market database which stores a variety of information related to each single market; among these are the price of traded commodities and the sold quantities per item. The SIMA database stores data retrieved from local surveys; i.e. 100 target markets constantly monitored thus allowing gathering monthly, and sometimes even weekly, bulletins on the state of each market. This database is not publicly accessible to date even if it will probably be in a near future. Data concerning traded volumes and types of commodities were used to classify the market according to the categories of assembly, wholesale and retail (given an importance factor of 3, 2 and 1 respectively), already detailed in paragraph 4.2.3.3, and to be used for **risk surface ii** and **iii** calculation. The final market dataset is composed of 114 markets that are a combination of the different market locations provided by the cited sources.

In Figure 36 the **risk surface i** is reported, obtained as explained in 4.2.3.1. This surface is composed by 114 areal units which represent the considered market catchments.

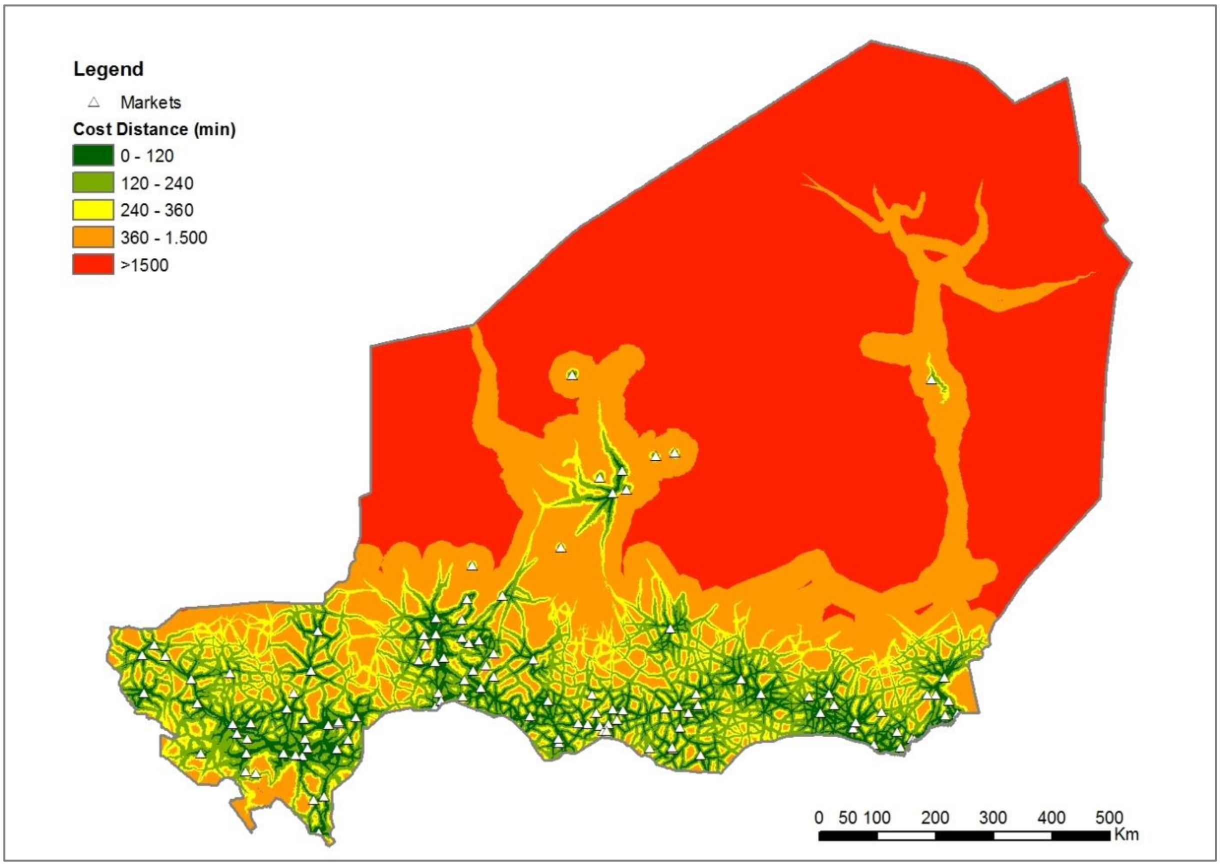

Figure 35 Cost distance calculated for 114 markets. Values are expressed in minutes needed to reach the nearest market along the shortest cost-distance path.

These surfaces are uniquely dependent on the physical accessibility of markets. Each surface unit is built by considering territorial continuity, presence of infrastructure and type of land cover. Noticeably, in high density market zones these surface units are limited in area by the presence of proximity markets. It should also be noted how risk surface units (i.e. 114 units as the number of considered markets) differ from the administrative level subdivisions (i.e. 36 subdivisions) that are subjected to different spatial criteria.

The **risk surface ii** for Niger, along with the market locations symbolized according to their importance, are reported in Figure 37. This surface is obtained, as detailed in section 4.2.3.3, by applying a spatial choice model based on Huff (1962) gravity spatial choice theory.

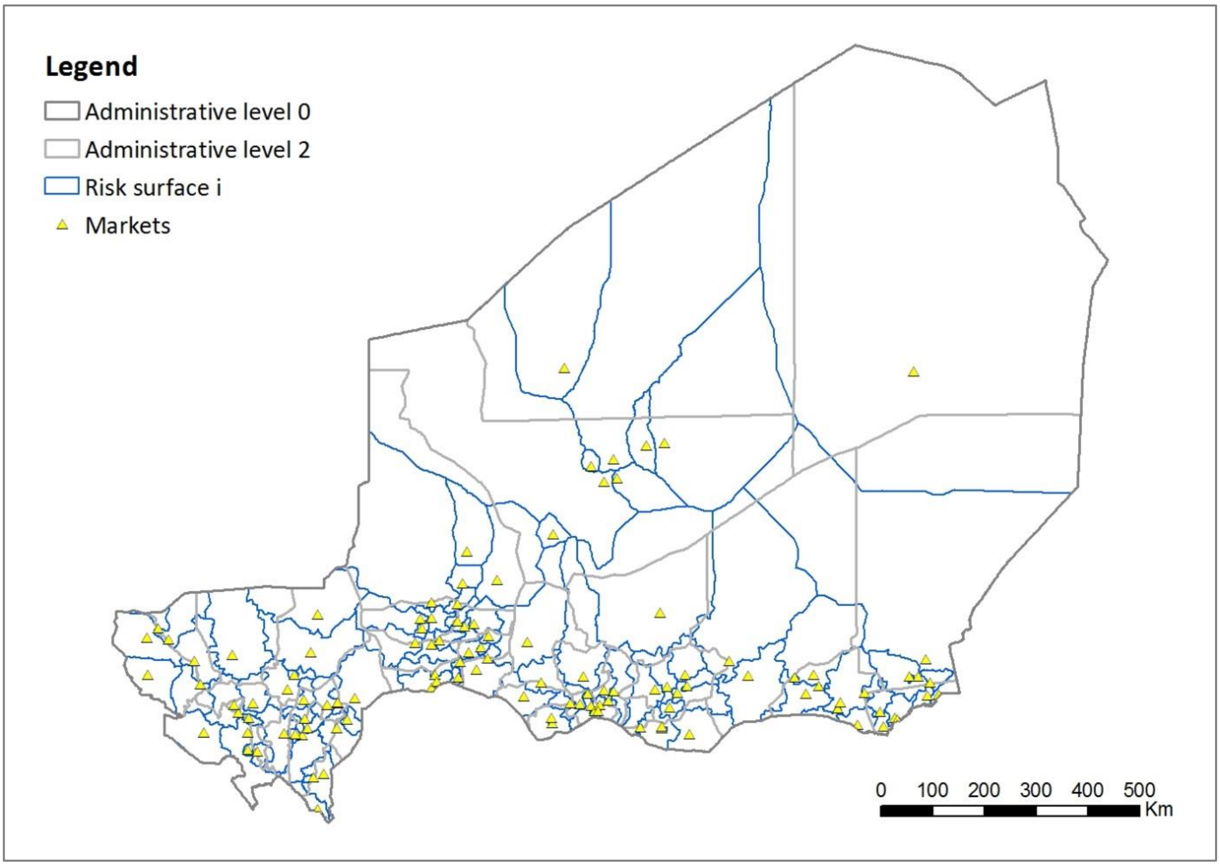

Figure 36 Risk surface i, calculated on the basis of the accessibility to Niger main markets.

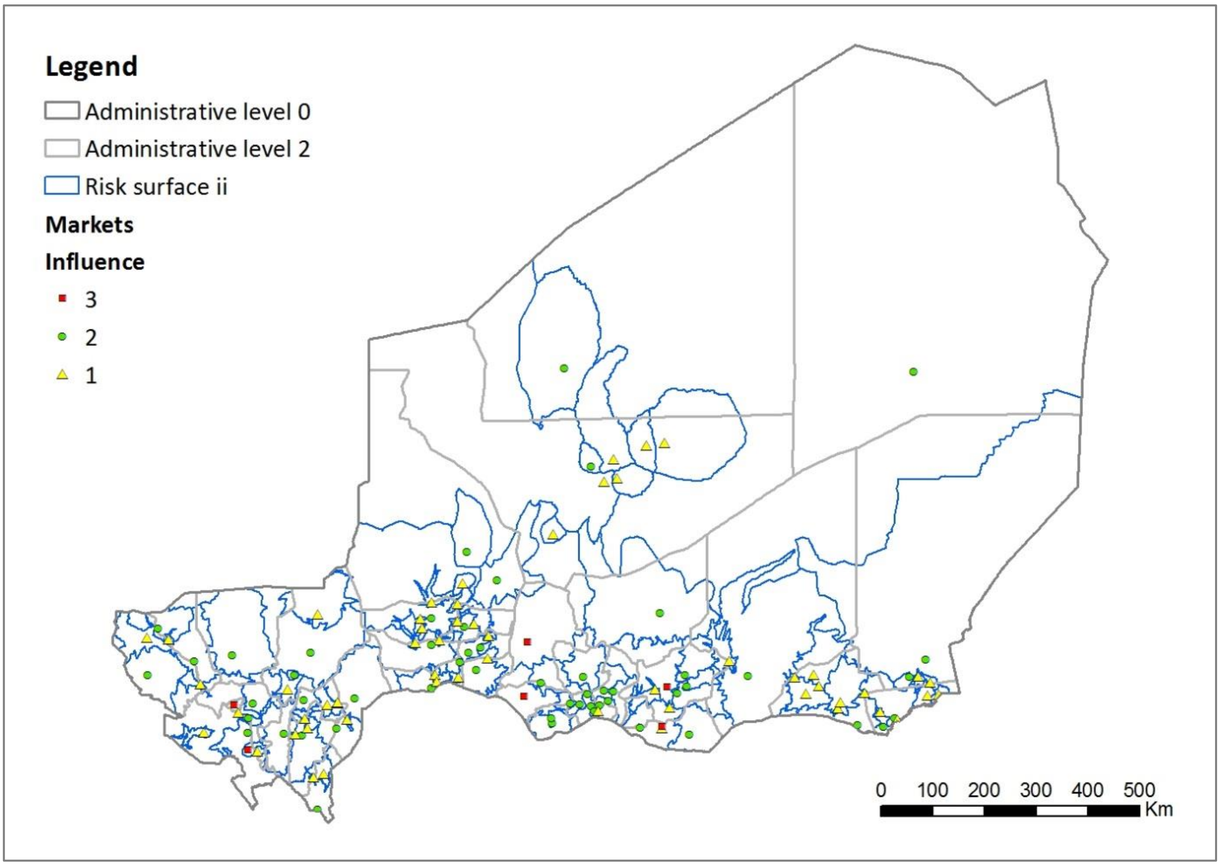

Figure 37 Risk surface ii calculated with the Huff gravity model for Niger main markets. Markets are represented according to their classification (3, 2 and 1 assigned to assembly, wholesale and retail markets respectively).

Local experts state that Niger markets are highly interconnected, in fact the Southern regions of the country are historically the most productive ones creating, during average production years, a surplus of staple food that is commercialized in Northern, traditionally deficit, regions. Moreover, foreign markets of bordering countries such as Burkina Faso, Benin, Nigeria and Chad furnish Niger markets with their products. In particular some of the biggest markets of the southern part of Niger are supplied by foreign merchandise; those in turn supply northern markets. Clearly, those kinds of trades vary year after year being influenced by agricultural production levels of single countries of the whole African region as well as by international price and market trends, thus their representation is beyond the scope of this work. However, the importance for food security of this transnational food trade is recognized by humanitarians; an attempt of capturing these transactions is made by USGS and Fews Net which provide country market flow maps for staple goods (see an example for Niger in Figure 40).

In the framework of the present study it has been decided to model only the Niger inner market flows by using the information included in the SIMA market database. The r**isk surface iii** was obtained by considering the relations existing among markets, which are reported in Table 7. It was decided to consider that the staple food market trades impact as for 30% of the weighted hazard (details in section 4.2.3.4) calculated for a particular market catchment: that is the weighted hazard calculated for markets that supply other inner Niger markets is distributed, as the 30% of its value, among the market catchments that are supplied. In an analogous way when a supplier market reports no detected weighted hazard, the correspondent supplied market sees their weighted hazard diminished by a 30% of their values.

The linkages among markets, reported in Table 7, are then represented in Figure 39.

Table 7 Niger market flow.

Market	Is supplied by	Supplies
ABALA MOULELA		Niamey
AYOROU GOUNGOU		
TAMASKE	Keita	
Tanout		
TCHADOUA	Aguie	
TCHINTABARADEN		
TCHINTABORAK		
TCHIROZERINE		
TERA		
TESSAOUA		
TILLABERI		
TORODI		
BADAGUICHIRI	Illela	
Toudoun Aggua		
TOUMOUR	Diffa	
TOUNFAFI LADAMA		

Market	Is supplied by	Supplies
TSERNAOUA	Birni n'konni	
ZINDER COMMUNE	Mirriah	
BAKIN BIRJI		
BALLEYARA		
BAMBAYE	Tahoua	
BANKILARE		
BARWA	Diffa	
BELLA ZENO		
BILMA		
BIRNI N'GAOURE		
ABALAK	Sabon Machi, Birni N'konni	Abardak, Agadez, Arlit, Bilma, Dabaga, Tabelot, Tchintaborak, Tchirozerine
BIRNI N'KONNI		
BOSSO		
BOULAMARI	Mainé-soroa	
BOUREIMI	Dogondoutchi	
BOUTTI I	Goudoumaria	
BOUZA		
DABAGA I		
DAKORO		
DAN SAGA (VA)	Aguie	
DANFAN	Tahoua	
ABARDAK (VA)		
DEBI	Aguie	
DIFFA		
DIOUNDIOU	Gaya	
DJADJI GANARAM	Goudoumaria	
Dogo		
DOGONDOUTCHI		
DOSSO		
DOUNGASS		
FALWEL		
FAMALE (VA)		Niamey
AFFALA	Tahoua	
FILINGUE		
FOURDIA		
Gada		
Gadira	Bosso	
GAGAMARI	Diffa	
GALMI		
GANGARA	Gazaoua	
GAYA		
GAZAOUA		
GOTHEYE		Niamey

Market	Is supplied by	Supplies
AGADEZ		
GOUDOUMARIA		
Gouloudji		
GOURE (CLA)		
GUIDAN-ROUMJI	Maradi	
GUIDAN IDER		
GUILLEY	Tahoua	
hamdallahi		
IBOHAMANE	Keita	
ILLELA	Badaguichiri	
KABELAWA	N'guigmi	
AGUIE		
KAOU (VA)		
Kassama		
Kazoé		
keguel	Maradi	
KEITA	Ibohamane	
KILAKAM		
KINJA HINDI		
KIRTACHI		Niamey
KOLLO		Niamey
KORE MAIROUA		
AMATALTAL		
KOURIA		
KOUTOUFANI	Dosso	
KOYGOROU	Dosso	
Léléwa	N'guigmi	
Liboré		
LOGA		
MADAOUA		
MADAROUNFA		
Madetta	Bouza	
MAGARIA		
ARLIT		
MAIJIRGUI	Tessaoua	
MAINE SOROA		
MALLAM KOUARA		
MARADI		
MATAMEY		
MAYAHI		
Miriah		
MOKKO	Dosso	
N'GUEL KOLO	Diffa	
N'GUIGMI		
AYAWANE	Bouza	

Market	Is supplied by	Supplies
NIAMEY I		
OUALLAM		
ROGOGO	Aguie	
SABON KAFI	Tanout	
SABON MACHI	Guidan Roumji	
SAY		
TABALAK	Tahoua	
TABELOT		
TABOTAKI	Bouza	
TAHOUA I		

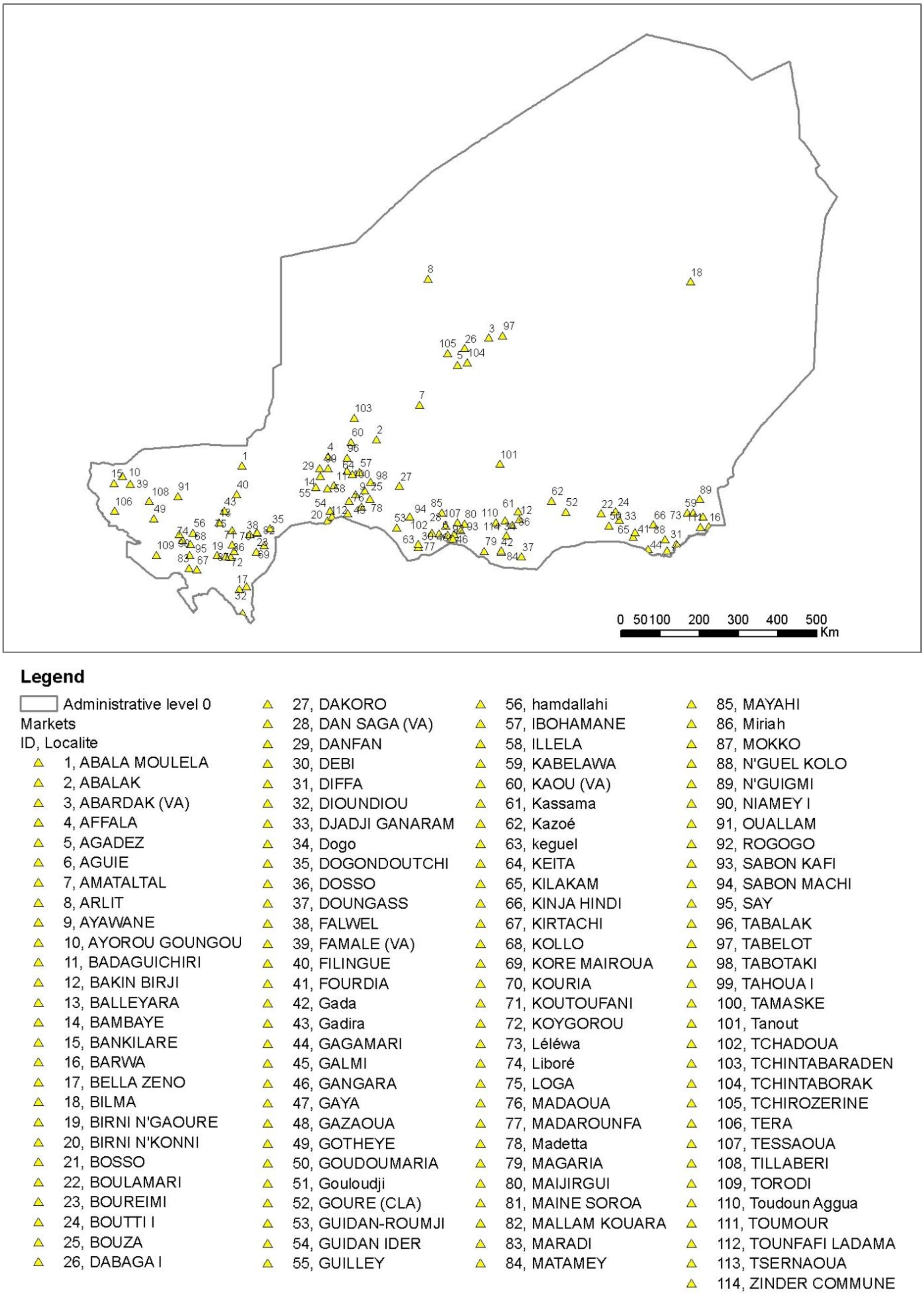

Figure 38 Niger markets.

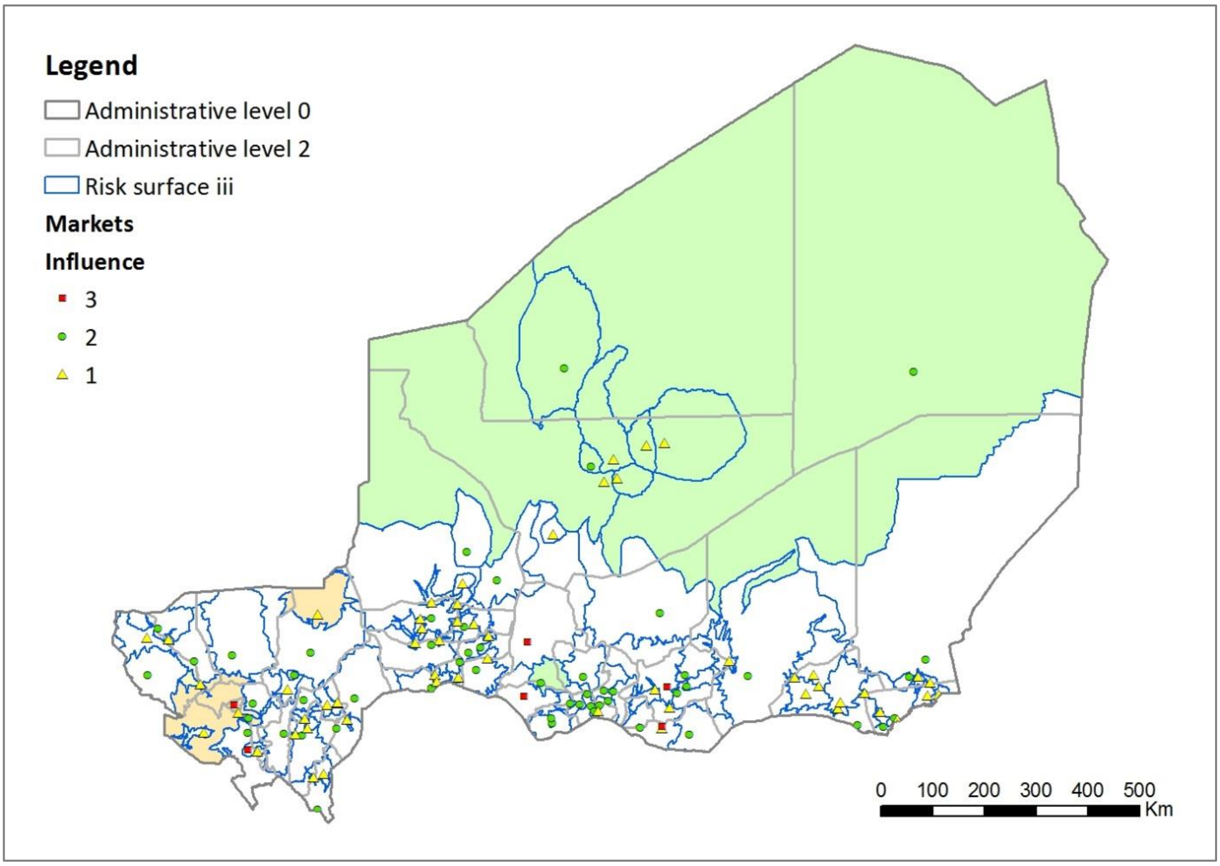

Figure 39 Risk surface calculated with the Huff gravity model for Niger main markets and then linked according to inner market flows. Highlighted in light green and light orange are the two main existing flows of food. Marketplaces are represented according to their classification.

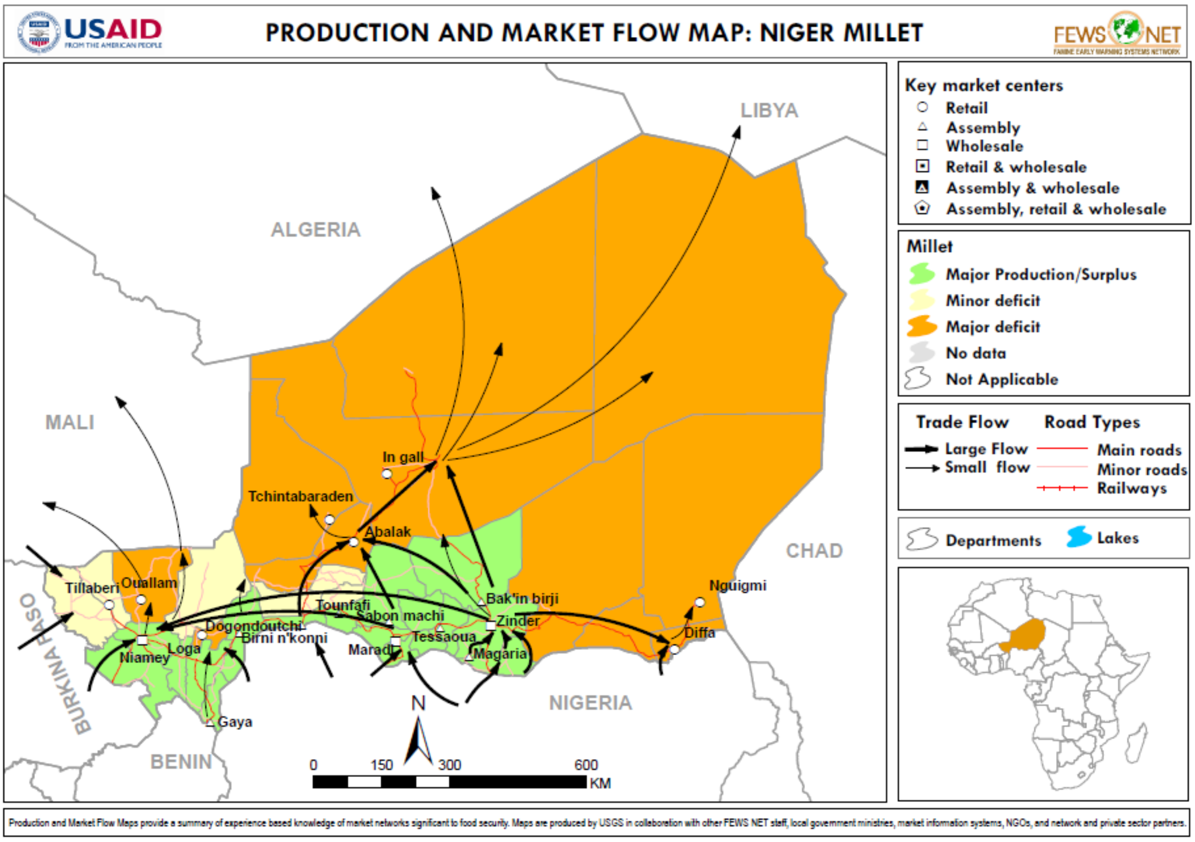

Figure 40 Production and market flow map for Niger millet produced by USGS and other Fews Net partners.

4.3.2 Mozambique

Mozambique is a country in the southeastern Africa, bordered by the Mozambique Channel (India Ocean) and located between South Africa and Tanzania.

According to 2013 estimates, it has a population of over 24 million, with a life expectancy of only 48 years. Aside from Niger and Democratic Republic of the Congo, the country ranks at the bottom of the 2012 Human Development Index, at 185th position out of 187 countries[19]. Moreover, with one third of the population and 43 percent of the children under five malnourished, Mozambique is dramatically food-deficit[20].

After the independence gained in 1975 from the Portuguese succeeding four centuries of colonialism, Mozambique fell in a long and destructive civil war lasted 16 years and ended in 1992. Since the end of the 1980s, the governments launched a series of macroeconomic and financial reforms designed to stabilize the economy. These steps, combined with donor assistance and with two decades of peace and stability, have led to outstanding improvements in the country growth rate (one of Africa's best performances). Due to its booming extractive industry and inflows of large investments (40% of its 2012 annual budget consist in foreign assistance), Mozambique has achieved a real GDP of 7.4 percent in 2012[21] [22].

Nevertheless, agriculture continues to be the pillar of the economy: the vast majority of the Mozambique workforce is employed in this sector, more than 80 percent, contributing to the 29.9% of the GDP in 2012[23]. It is essentially a subsistence agriculture conducted by smallholder farmers, which accounts for the 95% of the country agricultural production[24]. Nowadays the potential agricultural development is high, in fact only about 10 percent of the arable land is estimated to be cultivated (circa 5 million of hectares) (FAO, 2013).

Mozambique is characterized by a variety of agro-climatic zones ranging from arid and semi-arid areas, in the south and south-west, to sub-humid zones or humid highlands in the central and Northern provinces. Therefore, the southern zones with poor soil conditions and scarce rainfalls are the most vulnerable and are subject to recurrent droughts. Conversely, the northern and central areas are the most fertile with a high agro-ecological potential; generally, these provinces are already producing agricultural surpluses.

Tree crops such as coconut and cashew, particularly cultivated in the populated littorals of Inhambane and Gaza, are an important source of foreign exchange earnings. Other important productions include cotton (between 150,000 and 180,000 hectares), tobacco, oilseeds, tea, citrus and horticultural crops, particularly tomatoes. Most of the irrigated

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[19] http://hdr.undp.org/en/countries
[20] http://www.wfp.org/countries/mozambique/overview
[21] https://www.cia.gov/library/publications/the-world-factbook/geos/mz.html
[22] http://www.wfp.org/countries/mozambique/overview
[23] https://www.cia.gov/library/publications/the-world-factbook/geos/mz.html
[24] http://coin.fao.org/cms/world/mozambique/en/Home.html

areas (about 35,000 of 55,000 total hectares) are instead used by industrial plantations of sugarcane. With an overall 40,000 hectares, this cultivation has increased rapidly over the last decade reaching approximately 3 million tons by 2010. Major staples cultivated in Mozambique are maize and cassava followed by sorghum, beans, groundnuts, millet and rice. The seasonal calendar is characterized by two main growing seasons in the southern part of the country, while one season is found in the northern part (see Figure 42). Concerning breeding, cattle, goats and sheep are the principal livestock reared in extensive grass-based systems, whereas pigs and poultry are kept mainly at household level[25].

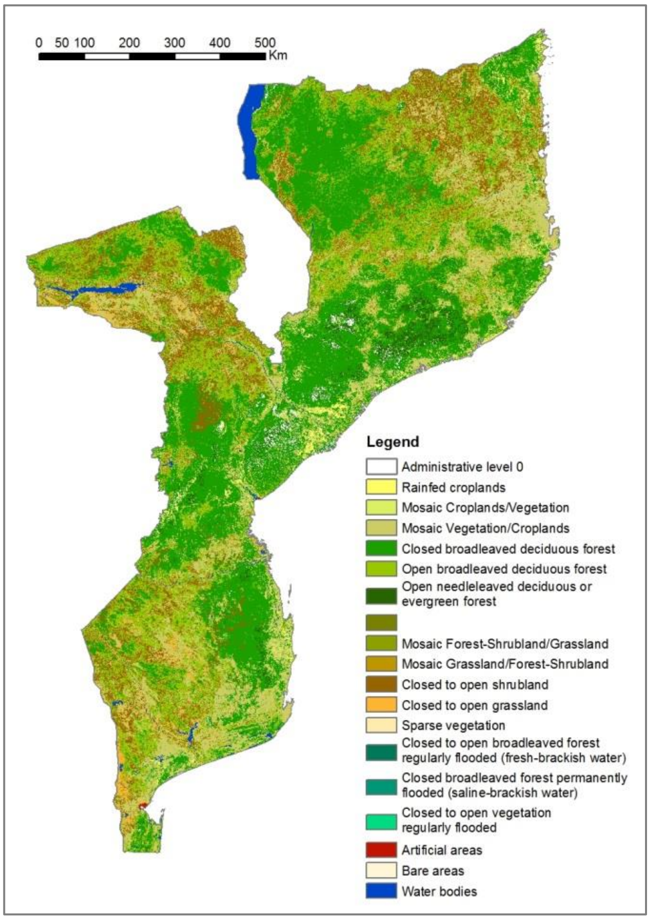


Figure 41 Mozambique land cover (source: ESA GlobCover, 300 m resolution, ©ESA 2010 and UCLouvain, ©ESA/ESA GlobCover Project).

Potentially, Mozambique could become not only a self-sufficient country in food production but even a regional exporter[26]. However, the agricultural systems are predominantly rain-fed, therefore the production can fluctuate widely from year to year[27]. Considering that the country is recurrently shocked by intensive climatic events (i.e. droughts, floods and cyclones) income from farming is often compromised contributing to food insecurity, while also causing loss of life, ruining livelihoods and damaging infrastructures. In this scenario, among African countries, Mozambique is the third most

[25] http://www.fao.org/docrep/012/ak350e/ak350e00.htm
[26] http://coin.fao.org/cms/world/mozambique/en/Home.html
[27] http://www.fao.org/docrep/012/ak350e/ak350e00.htm

affected by weather-related hazards. In average, floods occur every two to three years along the major river basins and more than 60 percent of the population lives in coastal areas which are vulnerable to rapid on-set disasters[28].

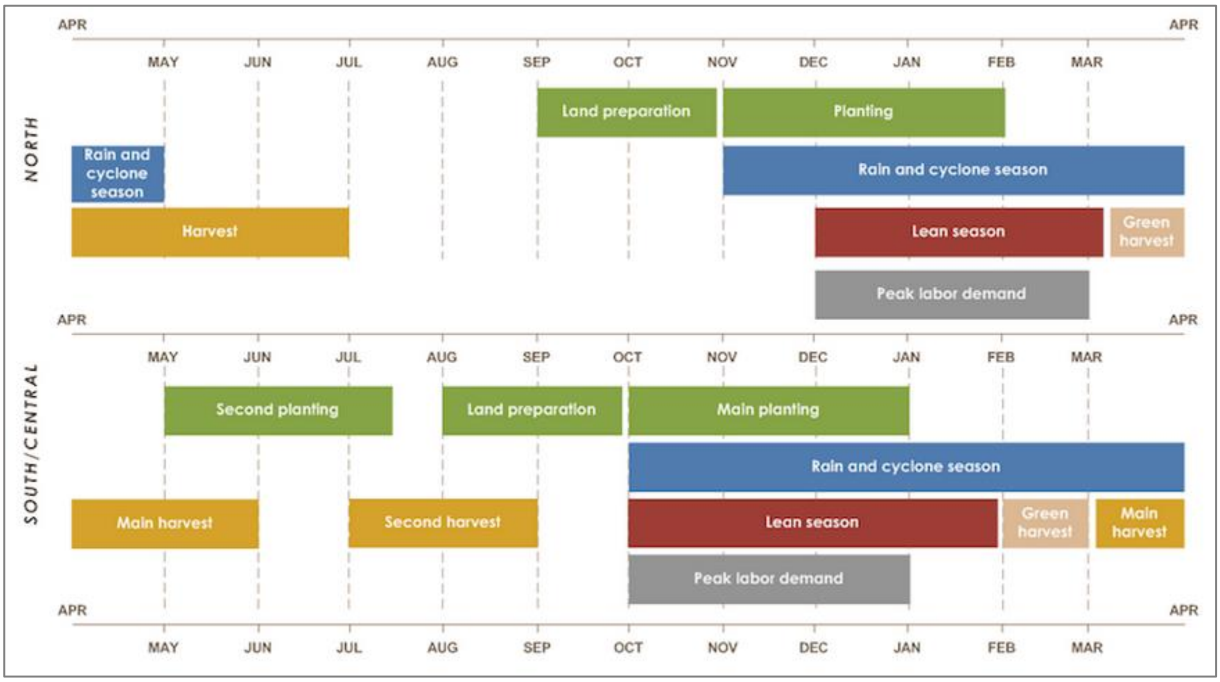


Figure 42 Mozambique seasonal calendar for a typical year (source: FEWS NET, retrieved from http://www.fews.net/southern-africa/mozambique accessed on 20/02/2014).

4.3.2.1 Applied model, input and intermediate results

As done for the case of Niger the most produced crop and the Crop Diversity Index were calculated on the basis of the FAO CountryStat database at the first level administrative boundaries. The results are reported in Table 8.

Table 8 Most produced crops and CDI given per Administrative level 1 of Mozambique.

Administrative level 1	Main Crop	CDI
NIASSA	CASSAVA	0,29
CABO DELGADO	CASSAVA	0,46
NAMPULA	CASSAVA	0,66
ZAMBEZIA	CASSAVA	0,63
TETE	MILLET	0,29
MANICA	MILLET	0,29
SOFALA	CASSAVA	0,25
INHAMBANE	CASSAVA	0,78
GAZA	CASSAVA	0,34
MAPUTO	CASSAVA	0,36

The CDI was used, as explained in 4.2.2, to weigh the Crop suitability index retrieved from GAEZ specifically for each of the most produced crop of Mozambique regions. The result of the process, after being weighted with the GMIA dataset too, is the agricultural vulnerability layer of Mozambique, which is provided in Figure 44.

[28] http://www.wfp.org/countries/mozambique/overview

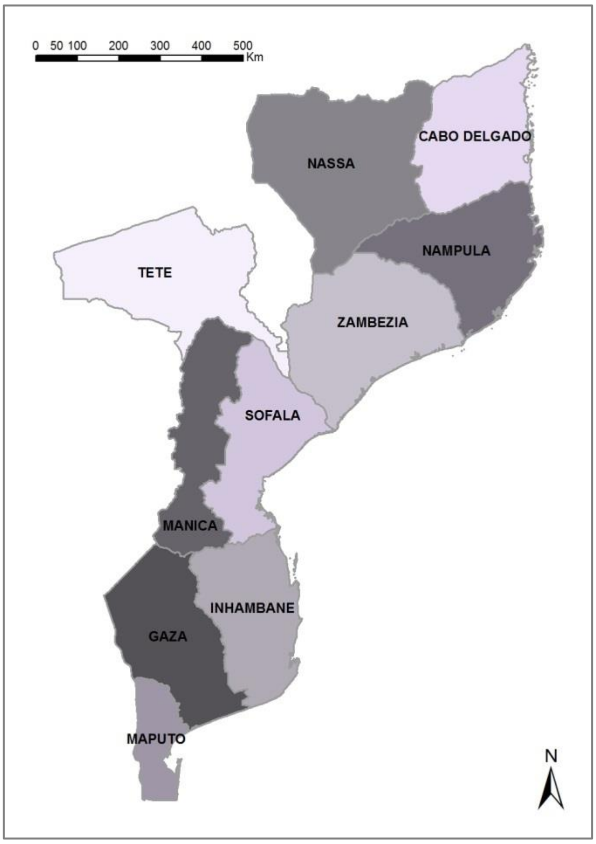


Figure 43 Mozambique administrative level I subdivision (source: GADM, 2012).

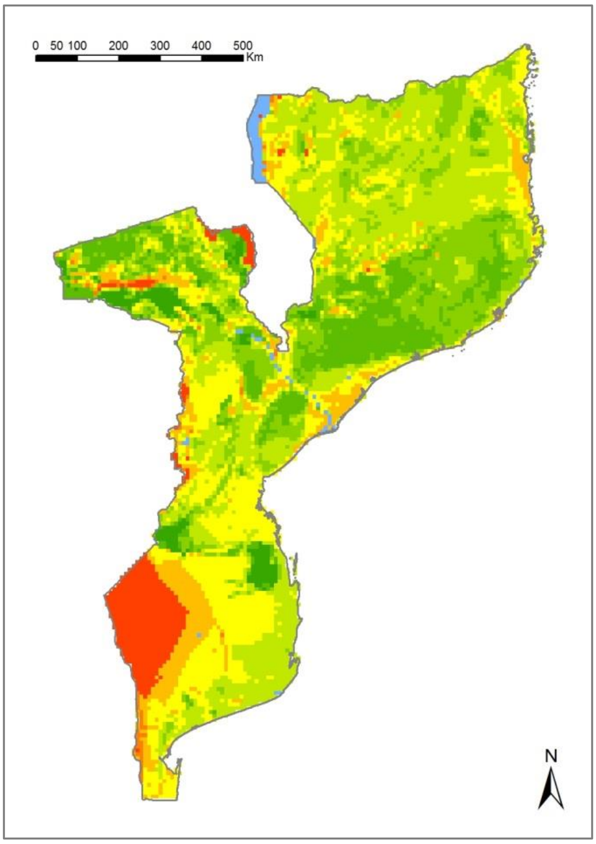


Figure 44 Agricultural vulnerability obtained for Mozambique.

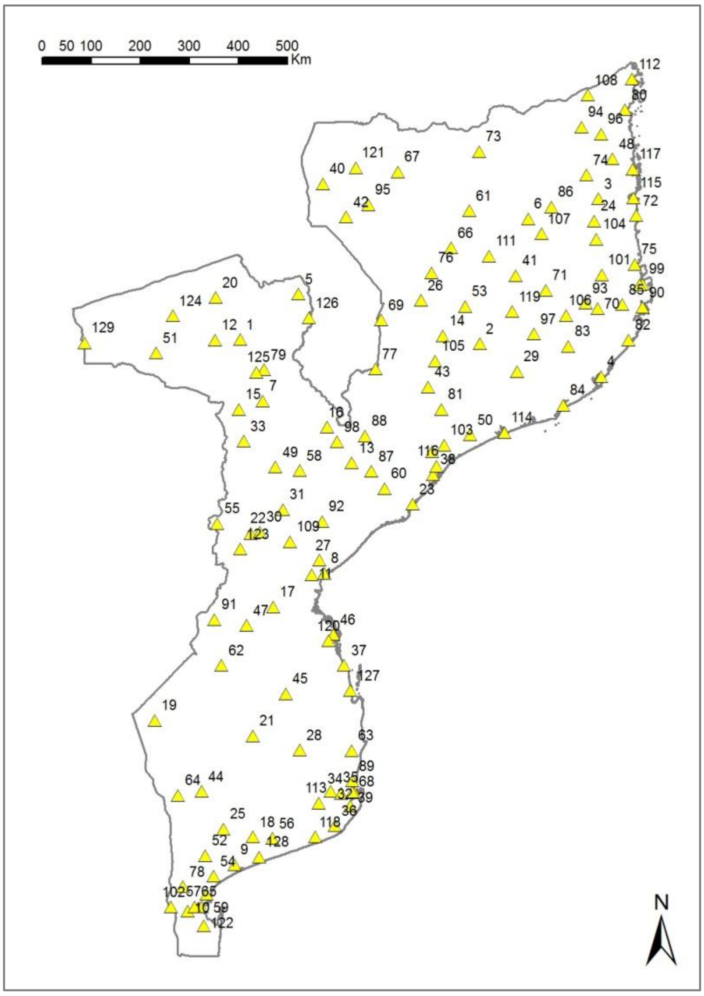
The **risk surface** for Mozambique was calculated in only two ways, alternatively considering:

i. The only accessibility model applied to the whole set of markets (called hereafter **risk surface i**);
ii. A gravity model applied after a market classification depending on their importance (called hereafter **risk surface ii**).

The **risk surface iii**, that considers the inner market flow of goods, couldn't be calculated in this case due to the lack of market networking data (i.e. traditional suppliers and supplied markets and quantity that are normally traded).

Market locations were retrieved partly from VAM-WFP global market database, partly from the national cities database (retrieved from the Instituto National de Estatistica-INE[29]) and partly from the GeoNames database[30]. In fact being the VAM-WFP dataset not considered exhaustive it has been decided to add to market list the county seats retrieved from INE and GeoNames. A total of 129 markets were eventually included in the present analysis (see Figure 45). A cost and a cost-distance raster were produced, as explained for Niger case, for Mozambique and are provided in Figure 46 and in Figure 47. On the basis of the cost-distance raster the **risk surface i** was produced (see Figure 48).

[29] http://www.ine.gov.mz/en/ accessed the 15th of March 2013.
[30] http://geonames.org/ accessed the 1st of March 2013.



Legend

Administrative level 0

Markets

1, Aldeia Chiuta
2, Alto Molócuè
3, Ancuabe
4, Angoche
5, Angónia
6, Balama
7, Barue
8, Beira
9, Bilene
10, Boane
11, Buzi
12, Cahora Bassa
13, Caia
14, Cha Gurue
15, Changara
16, Chemba
17, Chibabava
18, Chibuto
19, Chicualacuala
20, Chifunde
21, Chigubo
22, Chimoio
23, Chinde
24, Chiure
25, Chokwe
26, Cuamba
27, Dondo
28, Funhalouro
29, Gile
30, Gondola
31, Gorongoza
32, Guija
33, Guro
34, Homoine
35, Inhambane
36, Inharrime
37, Inhassoro
38, Inhassunge
39, Jangamo
40, Lago
41, Lalaua
42, Lichinga
43, Lugela
44, Mabalane
45, Mabote
46, Machanga
47, Machaze
48, Macomia
49, Macossa
50, Maganja
51, Magoe
52, Magude
53, Malema
54, Manhica
55, Manica
56, Manjacaze
57, Maputo
58, Maringue
59, Marracuene
60, Marromeu
61, Marrupa
62, Massangena
63, Massinga
64, Massingir
65, Matola
66, Maua
67, Mavago
68, Maxixe
69, Mecanhelas
70, Meconta
71, Mecuburi
72, Mecufi
73, Mecula
74, Meluco
75, Memba
76, Metarica
77, Milange
78, Moamba
79, Moatize
80, Mocimboa da Praia
81, Mocuba
82, Mogincual
83, Mogovolas
84, Moma
85, Monapo
86, Montepuez
87, Mopeia
88, Morrumbala
89, Morrumbene
90, Mossuril
91, Mossurize
92, Muanza
93, Muecate
94, Mueda
95, Muembe
96, Muidumbe
97, Murrupula
98, Mutarara
99, Nacala
100, Nacala-a-Velha
101, Nacaroa
102, Namaacha
103, Namacurra
104, Namapa
105, Namarroi
106, Nampula
107, Namuno
108, Nangade
109, Nhamatanda
110, Nicoadala
111, Nipepe
112, Palma
113, Panda
114, Pebane
115, Pemba
116, Quelimane
117, Quissanga
118, Regedor Zavala
119, Ribaue
120, Ruralato do Govuro
121, Sanga
122, Sao Roque Matutuine
123, Sussundenga
124, Tambara
125, Tete
126, Tsangano
127, Vilankulo
128, Xai Xai
129, Zumbo

Figure 45 Mozambique markets.

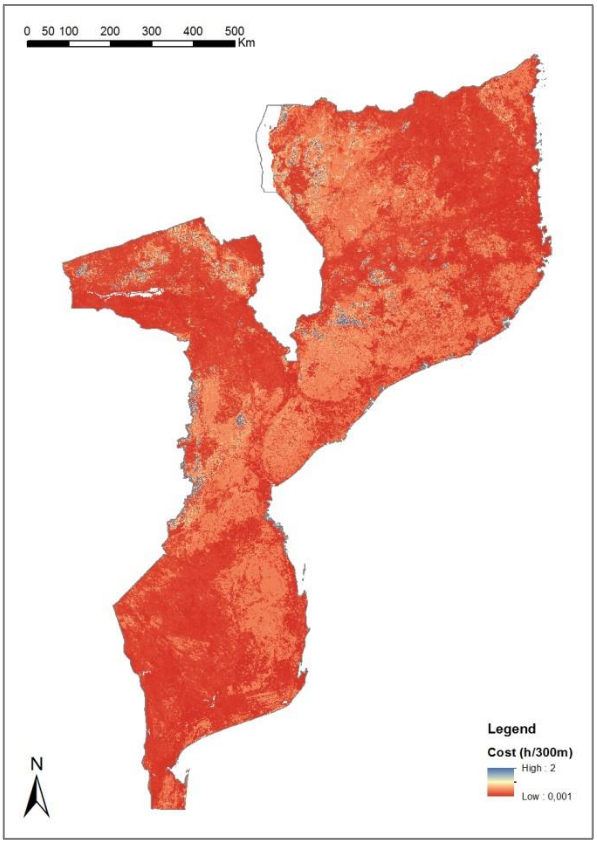


Figure 46 Mozambique cost raster.

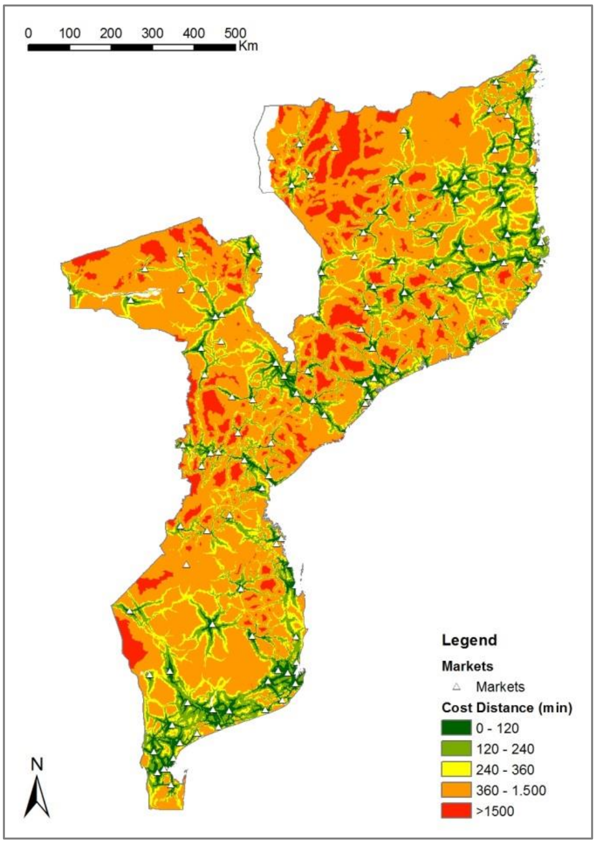


Figure 47 Cost distance calculated for 129 Mozambique markets.

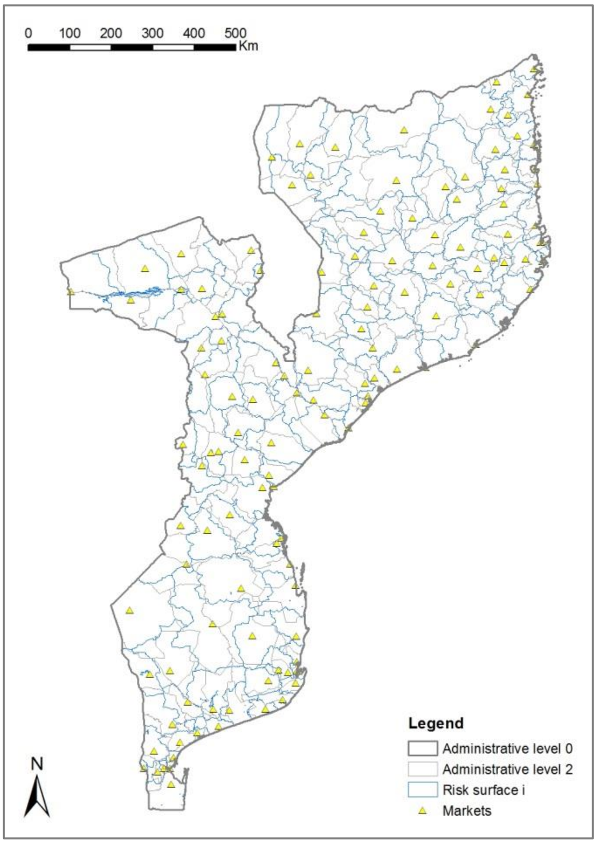


Figure 48 Risk surface calculated on the basis of the accessibility to Mozambique main markets (i.e. risk surface i).

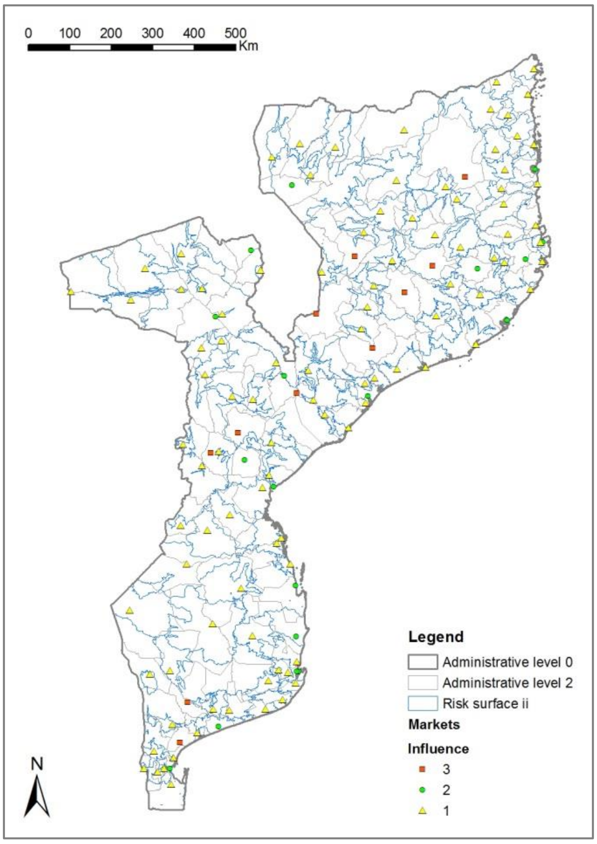


Figure 49 Risk surface calculated with the Huff gravity model for Mozambique main markets (i.e. risk surface ii).

In order to produce the **risk surface ii** the attractiveness values of each of the Mozambique markets were retrieved from the analysis of Mozambique market flow maps of the most important traded crops (an example is given in Figure 50). On the basis of the market category used in the market flow maps (i.e. Wholesale, Assembly and Retail) an importance factor related to the type of market was attributed to the correspondent market (i.e. 3 and 2 for the wholesale and assembly type respectively); whether the market didn't appear in the market flow maps its importance value was set to 1 (i.e. retail market). The resultant **risk surface ii** is reported in Figure 49.

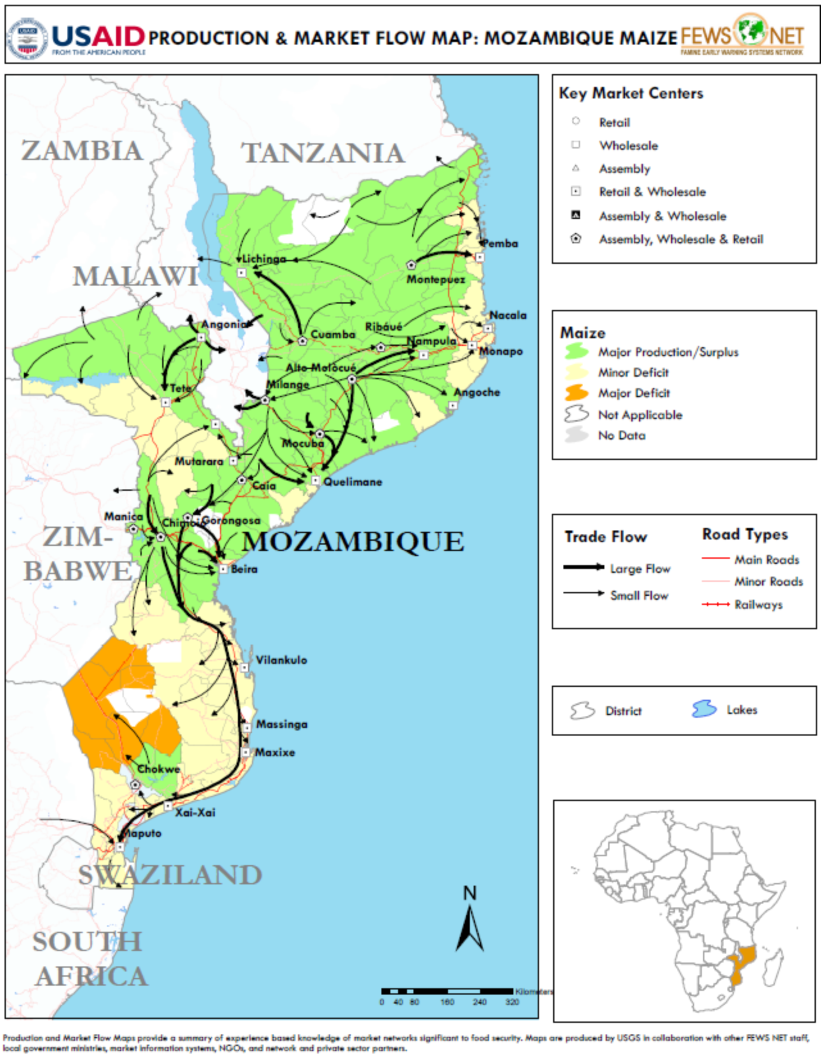


Figure 50 Production and market flow map for Mozambique maize produced by USGS and other Fews Net partners.

4.4 Evaluation phase

In the present research the aim of the evaluation phase was to compare final alerts, obtained by applying the vulnerability model to the hazard product produced by ITHACA EWS, with food security data. Rather than being only the last stage of the presented study, the quest for and selection of validation data have proved to be an arduous task. In fact it must be pointed out that EWSs are rarely validated with truth data on a historical basis, this is the reason why a particular attention was given in this work to the evaluation phase and thus to the selection of truth data.

In particular if one aims at validating a drought EWS, he will encounter the following issues: firstly, drought impacts are various thus not univocally recognized and measured; secondly historical impact data, aggregated on the basis of a more detailed level than the country one, are rarely available; thirdly, when data at sub-country level exist, they are rarely organized in geospatial well-structured databases and are frequently produced by different sources.

The first mentioned issue was addressed by deciding to use food security data as impact data, targeting one of the main indirect shocks caused by drought. Second and third issues were solved by using regional food security outlooks produced as maps with a common interpreting scale since 2008, thus usable for qualitative evaluation purposes for different countries, and locally retrieved food security data aggregated at second administrative subdivision, usable only in particular cases.

Eventually for the purpose of validating the Final Alerts two types of data were used:

- Food Security Outlook and Assessments produced by Fews Net, that have been used for a qualitative evaluation (see 4.4.1);
- Food Security Assessments (FSA) produced by WFP Niger offices, which have been used for a quantitative evaluation in the Niger case (see 4.4.2).

4.4.1 Qualitative evaluation

In order to perform a qualitative evaluation of produced final alerts, Fews Net Food Security Assessments and Outlooks were used. The aim of the qualitative evaluation is to compare the two products (i.e. Fews Net Outlooks and Final Alerts of the presented model combined with ITHACA EWS hazard). The comparison is performed year per year for the available time series (further details are found in section 5.1).

The Fews Net project has the primary mandate to produce famine early warning outputs. Fews Net is the only global provider of famine assessments and outlooks. On the project website[31] these outlooks are made available on quarterly basis, providing food security conditions for the coming three to six months (an example is provided in Figure 12). These data are available as text bulletin and as shapefiles with regional and, less frequently, country extent. Fews Net classification is here considered useful because: (i) areas classified do not normally follow any administrative boundary; (ii) food security projected severity is classified according to the Integrated Food Security Phase Classification (IPC 2.0)[32] scale; (iii) it is the only global monitoring system that provides maps outlining the degree of food security and its extent; (iv) the same methodology is used for producing famine alerts for different countries, thus allowing comparing the food security situation of those different countries and regions. Moreover, the IPC scale is widely accepted by the humanitarian community and offers classification standards that permit users worldwide to understand and use a common reference language. The reference table for

[31] http://www.fews.net/

[32] http://www.fews.net/our-work/our-work/integrated-phase-classification

IPC classification is reported in Figure 51, where impacts and responses are also shown for each of the five classification phases.

	Phase 1 Minimal	Phase 2 Stressed	Phase 3 Crisis	Phase 4 Emergency	Phase 5 Famine
Phase Name and Description	*More than four in five households (HHs) are able to meet essential food and non-food needs without engaging in atypical, unsustainable strategies to access food and income, including any reliance on humanitarian assistance*	*Even with any humanitarian assistance at least one in five HHs in the area have the following or worse:* *Minimally adequate food consumption but are unable to afford some essential non food expenditures without engaging in irreversible coping strategies.*	*Even with any humanitarian assistance at least one in five HHs in the area have the following or worse:* *Food consumption gaps with high or above usual acute malnutrition* *OR* *Are marginally able to meet minimum food needs only with accelerated depletion of livelihood assets that will lead to food consumption gaps.*	*Even with any humanitarian assistance at least one in five HHs in the area have the following or worse:* *Large food consumption gaps resulting in very high acute malnutrition and excess mortality* *OR* *Extreme loss of livelihood assets that will lead to food consumption gaps in the short term.*	*Even with any humanitarian assistance at least one in five HHs in the area have an extreme lack of food and other basic needs where starvation, death, and destitution are evident.* *(Evidence for all three criteria of food consumption, wasting, and CDR is required to classify Famine.)*
Priority Response Objectives	Action required to Build Resilience and for Disaster Risk Reduction	Action required for Disaster Risk Reduction and to Protect Livelihoods	**Urgent Action Required to:** → Protect livelihoods, reduce food consumption gaps, and reduce acute malnutrition	Save lives and livelihoods	Prevent widespread mortality and total collapse of livelihoods
Area Outcomes (directly measured or inferred): Food Consumption and Livelihood Change	More than 80% of households in the area are able to meet basic food needs without engaging in atypical strategies to access food and income, and livelihoods are sustainable	Based on the IPC Household Group Reference Table, at least 20% of the households in the area are in Phase 2 or worse	Based on the IPC Household Group Reference Table, at least 20% of the households in the area are in Phase 3 or worse	Based on the IPC Household Group Reference Table, at least 20% of the households in the area are in Phase 4 or worse	Based on the IPC Household Group Reference Table, at least 20% of the households in the area are in Phase 5
Area Outcomes (directly measured or inferred): Nutritional Status*	Acute Malnutrition: <5% BMI <18.5 Prevalence: <10%	Acute Malnutrition: 5–10%, BMI <18.5 Prevalence: 10–20%	Acute Malnutrition: 10–15% OR > usual and increasing BMI <18.5 Prevalence: 20–40%, 1.5 x greater than reference	Acute Malnutrition: 15–30%; OR > usual and increasing BMI <18.5 Prevalence: >40%	Acute Malnutrition: >30% BMI <18.5 Prevalence: far > 40%
Area Outcomes (directly measured or inferred): Mortality*	CDR: <0.5/10,000/day U5DR: ≤1/10,000/day	CDR: <0.5/10,000/day U5DR: ≤1/10,000/day	CDR: 0.5–1/10,000/day U5DR: 1–2/10,000/day	CDR: 1–2/10,000/day OR >2x reference U5DR: 2–4/10,000/day	CDR: >2/10,000/day U5DR: >4/10,000/day

Figure 51 IPC Acute Food Insecurity Reference Table for Area Classification (source: IPC Global Partners, 2012).

Fews Net methodology (Hillbruner, 2012) is based on scenario development: that is once the area and the household group is targeted, food security actual condition are firstly analyzed; then food security outcomes are investigated by means of a set of indicators; the targeted group is thus classified on the basis of food security conditions and outcomes with the Food Security Classification Protocols. In the second phase both normal factors and shocks susceptible to be relevant for food security are identified, that is to determine possible food security scenarios during the period of interest; in this phase various assumptions about timing, duration and severity of likely shocks have to be made. At this point expected impacts on income and food sources of the targeted group should be identified. The next stage implies the identification of group responses to the identified shocks impacting food access and earnings. Eventually, projected food security conditions and areas are classified and described through the Food Security Classification Protocols.

4.4.2 Quantitative evaluation

One of the most challenging issues of the presented work is the validation of the produced outputs. As a matter of fact a verified accordance with truth data should be considered essential in the developing of monitoring and early warning systems. Unfortunately, due to objective difficulty of the drought impact definition and consequently lack of truth data, existing EWS are seldom if ever validated. In the present case it turned out to be very difficult to find quantitative data related to measured food security at global extent, which is the indirect drought impact targeted by the present study. In addition, even when country-specific datasets are to be considered, they happen to be rarely accessible remotely. Eventually, a field mission was deemed necessary to retrieve historical food security data at sub-country level. WFP Niger bureau hosted the author for a month permitting data collection and furnishing unavoidable interpretation support provided by the local staff.

Therefore the quantitative evaluation was conducted with data resuming food insecurity conditions for Niger administrative level 2 subdivisions (Food Security Assessments, FSA) retrieved locally. These data are produced yearly, when field security conditions are met, by the WFP country office on the basis of field surveys. A set of target households is constantly monitored in order to measure 5 indicators (i.e. called "active indicators"):

- Food consumption score;
- Coping strategy index ;
- Share of expenditure devoted to food;
- Tropical Livestock Units (TLUs) owned;
- Duration of food stock.

Following the data collection, a Principal Component Analysis (PCA) is performed in order to identify indicator values that describe analogous food security conditions. The PCA allows to: determine households groups characterized by the same food security status, and to classify these groups on the basis of their level of food security. As a result the population of each department (departments of Niger are reported in Figure 52), after extrapolation, is categorized in classes of food insecurity, i.e. (i) percentage of food secure; (ii) percentage of moderate food insecure; (iii) percentage of severe food insecure.

FSA data are used by the local WFP staff to target the beneficiaries and the extent of WFP interventions. The assessments are conducted monthly but evaluated and used or at the beginning of the lean period or at the end of the harvesting. It should be noted that the above-mentioned indicators are likely to identify food insecurity conditions attributable not only to drought events but also to generic exceptional contexts such as floods, pests, human conflicts, etc.

The available FSA time series obtained by local WFP office staff is reported in Table 9 whereas the secondary level subdivisions of Niger are reported in Figure 52.

Table 9 Food Security Assessment data for Niger departments. Values are expressed in affected population percentage. 2013 values are estimation as of October 2013 and are not retrieved from field surveys.

	2006			2007			2008			2009			2011			2013
Department	Moderate	Severe	Total	Moderate	Severe	Total	Moderate	Severe	Total	Moderate	Severe	Total	Moderate	Severe	Total	Total
Aguie	21,8	1	22,8	5,5	8,9	14,4	18,8	4,1	22,9	28,3	34,1	62,4	19,1	6,6	25,7	44,0
Arlit	32,1	9,7	41,8	N.A.	N.A.	N.A.	20,9	5	25,9	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	13,4
Bilma	17,2	0,5	17,7	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Birni N'gaoure	22,5	13,8	36,3	24,1	14,3	38,4	14,4	6,4	20,8	39,9	5,8	45,7	16,2	4,4	20,6	26,7
Birni N'konni	14,7	2,1	16,8	25	3,1	28,1	15,9	7,3	23,2	21,5	8,4	29,9	12,5	5,6	18,1	30,4
Bouza	34,9	7,1	42	48,1	6,6	54,7	31,9	10,7	42,6	15,5	37,6	53,1	33,7	13,6	47,3	46
Dakoro	15,9	10,2	26,1	5,3	18,7	24	3,6	2,6	6,2	27,5	12	39,5	12,9	4,2	17,1	15,6
Diffa	5,3	0,6	5,9	41,4	7,3	48,7	18,4	17,3	35,7	22,4	10,3	32,7	29,6	5	34,6	8,8
Dogondoutchi	19,4	1,4	20,8	17	13,1	30,1	8,6	1,7	10,3	25,8	14,9	40,7	21	4,2	25,2	54,4
Dosso	26,9	3,7	30,6	24,1	14,3	38,4	22,7	7,2	29,9	32,9	18,6	51,5	31,2	1,4	32,6	30,9
Filingue	23,1	5,1	28,2	37,2	15,5	52,7	14,2	4,9	19,1	27,2	17,8	45	31,2	9,6	40,8	20
Gaya	6,4	2,6	9	24,1	14,3	38,4	19,5	5,5	25	20,7	8,6	29,3	17,4	1	18,4	49,4
Goure	14,7	16	30,7	33,2	11,8	45	13,3	13	26,3	17,9	6,1	24	23,6	7,2	30,8	25,5
Guidan Roumji	22,4	10,9	33,3	20,4	16	36,4	21,2	8,4	29,6	29,7	26	55,7	23,2	3,5	26,7	26,1
Illela	24,5	14,8	39,3	14	9	23	22,2	21,1	43,3	27	19,3	46,3	23,4	15,5	38,9	62,2
Keita	18,7	33,2	51,9	42,7	15,2	57,9	28,9	17,2	46,1	19,6	37,1	56,7	30	10,6	40,6	54,5
Kollo	19,5	1,5	21	21,6	24,7	46,3	17,8	7,2	25	36,1	17,3	53,4	32,2	8,3	40,5	17,8
Loga	31,2	16,9	48,1	24,1	14,3	38,4	10,5	2,6	13,1	30,4	14,1	44,5	34,4	9,5	43,9	44,2
Madaoua	18,9	6	24,9	9,2	8,8	18	15,6	10,6	26,2	27	28,7	55,7	30,7	1,1	31,8	35,2
Madarounfa	15,4	8,7	24,1	8	8,4	16,4	9,8	3,3	13,1	31	25,9	56,9	15,4	5,2	20,6	31,9
Magaria	15,1	6,4	21,5	33,8	13	46,8	12,8	5,9	18,7	34,3	9,9	44,2	40,4	2,3	42,7	7,9
Maine-soroa	20,2	1,6	21,8	N.A.	N.A.	N.A.	16,8	11,5	28,3	21,8	23,3	45,1	29,3	8,8	38,1	12
Matamey	11,8	3	14,8	20,1	8,9	29	21,8	8,5	30,3	20,8	13,5	34,3	25,2	2,2	27,4	9,4
Mayahi	25,6	0	25,6	11,3	9,6	20,9	10,1	2,8	12,9	23,3	26,6	49,9	28,4	11,5	39,9	27,0

Miria	20,4	12,8	33,2	16,3	9,5	25,8	19,2	7,8	27	27,1	14,9	42	18,6	4,2	22,8	26,6
N'guigmi	20,4	1,1	21,5	N.A.	N.A.	N.A.	10	13	23	10,8	6,7	17,5	25,2	1,7	26,9	1,9
Niamey	24,3	1,5	25,8	17,5	18,4	35,9	12,8	14,9	27,7	36,4	6,5	42,9	22	7,3	29,3	N.A.
Ouallam	17	40,8	57,8	14,5	33	47,5	18,2	13,7	31,9	20,5	64,1	84,6	27,5	13,1	40,6	33,8
Say	20	1,5	21,5	8,5	15,1	23,6	2,3	2,6	4,9	25,2	1,6	26,8	9,5	7	16,5	36,9
Tahoua	19,5	31,9	51,4	32,2	5,5	37,7	5,3	7,8	13,1	31,4	28,9	60,3	26,9	9,9	36,8	30,1
Tanout	46,7	4,7	51,4	13	4,9	17,9	4,8	8,1	12,9	31,4	29,3	60,7	53,5	3,5	57	23,6
Tchighozerine	15,6	5,2	20,8	9,1	13,9	23	24,8	35,3	60,1	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	18,9
Tchin Tabaradene	29	12,1	41,1	34	9,3	43,3	21,7	51,9	73,6	12,8	12,2	25	14,5	4,9	19,4	39,7
Tera	19,8	2	21,8	32,2	9,2	41,4	16,3	25,4	41,7	27,2	17,2	44,4	32,4	8,7	41,1	54,1
Tessaoua	10,5	5,5	16	15,7	7	22,7	18,5	22,8	41,3	20,6	56,9	77,5	27,6	9	36,6	19,5
Tillaberi	26	33,9	59,9	14	5,1	19,1	15	33,1	48,1	31,2	32,4	63,6	14,6	8,3	22,9	31,6

FSA data of 2010 are lacking due to the military coup occurred the same year in January, that most probably made impossible to conduct field surveys for the whole year. Data from Arlit and Bilma departments are also lacking for almost the whole time series due to the security issues persistent in the desert region in the Northern part of the country.

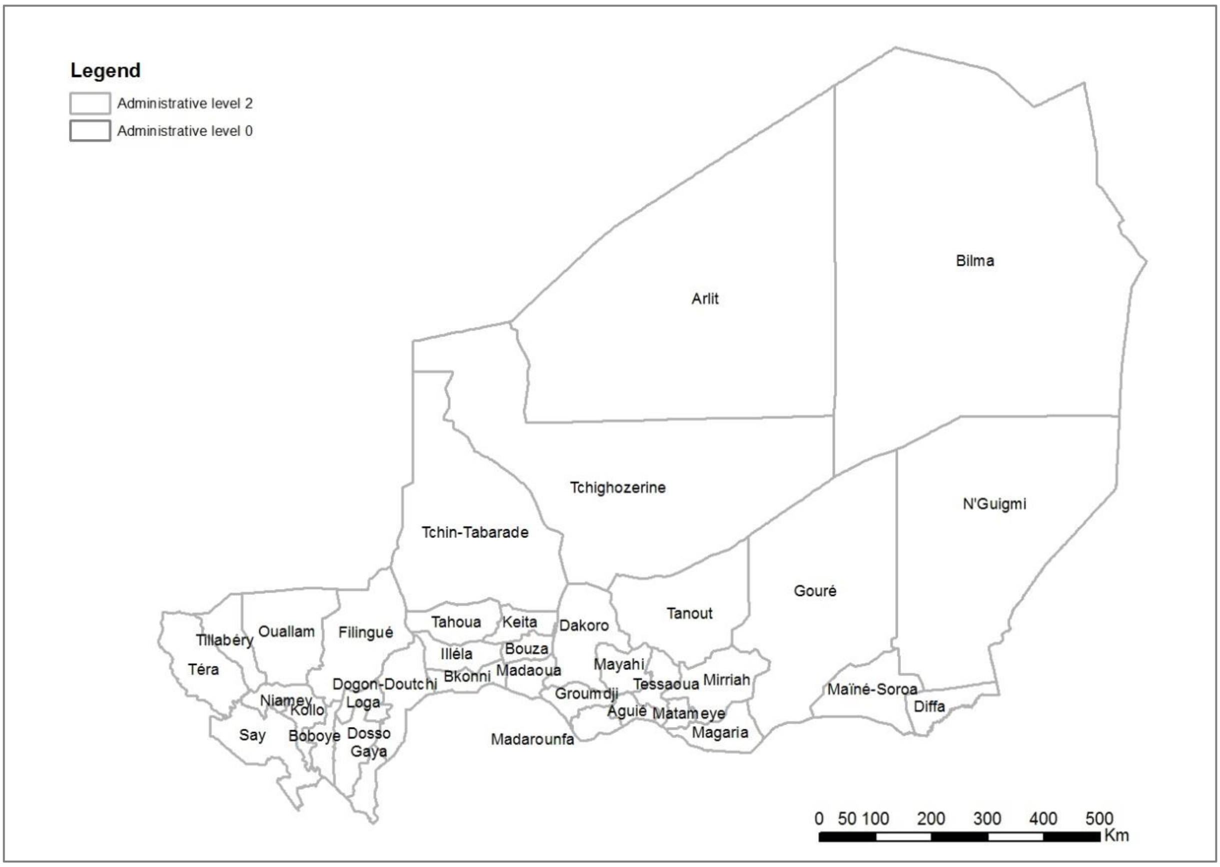


Figure 52 Niger administrative level 2 subdivision (i.e. departments).

5 RESULTS

In this chapter the results of the evaluation process of the final alerts (hereafter called “model alerts” as well) are presented. In the first section the results of the qualitative evaluation are presented while in the second section the quantitative one is presented. A third section is devoted to the discussion of both types of evaluation assessments.

5.1 Qualitative evaluation

The qualitative evaluation was performed by means of Fews Net products (refer to paragraph 4.4.1 for more details). The final alerts, produced by applying the vulnerability model to the hazard produced by ITHACA, were compared with Fews Net maps produced from 2008 to 2013. Both case studies were considered in the qualitative evaluation process and the three risk surfaces were evaluated as well (i.e. **risk surface i** calculated on the basis of the easiness to reach marketplaces; **risk surface ii** which exploits a spatial gravity model; **risk surface iii** that integrates the gravity model with market trade information).

Three types of outputs are produced periodically by Fews Net: food security current conditions, food security outlook and food security updates. The first states the actual food security conditions, the second provides projections of food security conditions on the three to six next months on the basis of both most likely and worst future scenarios; while the third type provides updates of an already disseminated outlook on the basis of occurred changes in food security conditions. Considering that the final alerts, produced with the application of the presented vulnerability model to the case studies, are calculated taking into account the whole vegetation growing season, i.e. at the end of it, it has been decided to use the three types of Fews Net products according to the period in which they were produced and made public. When available, the priority of use was given to food security current conditions or updates that, instead of being based on projected assumptions, are the outcomes of field indicator analysis.

A selection of model alert maps and of food security outlook is provided in the following paragraphs, grouped per country and per year. The alert values obtained with the model are expressed in the same unit in which the NDVI anomalies are expressed (percentage of anomaly with respect to the average of the time series) while Fews Net map values are expressed through the IPC scale (for more details see Figure 51).

Fews Net maps have been downloaded as bulletin in pdf formats from ReliefWeb website[33]; the available bulletin time series starts from 2008, so does the qualitative evaluation.

[33] http://reliefweb.int/

Niger food security 2008

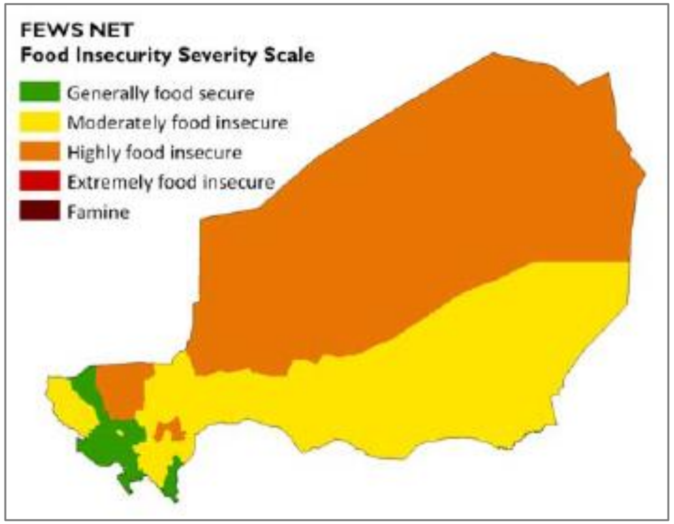


Figure 53 Food security assessment as of July 2008 (FEWS NET).

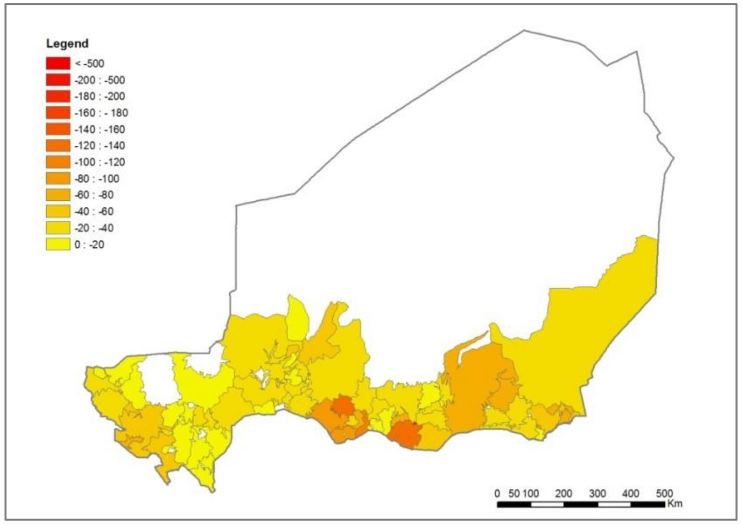


Figure 55 Model alert for 2008 harvest season for risk surface ii.

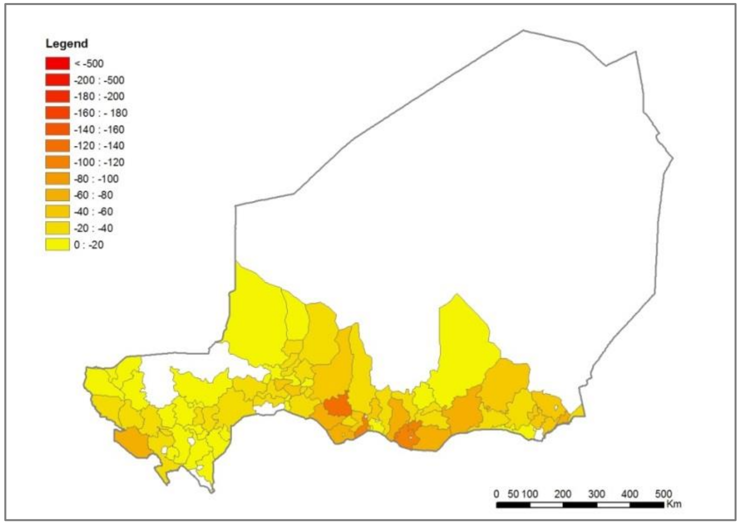


Figure 54 Model alert for 2008 harvest season for risk surface i.

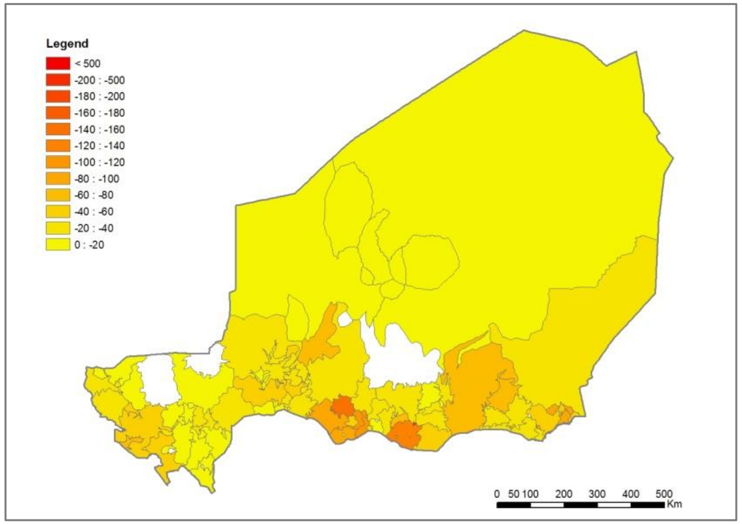


Figure 56 Model alert for 2008 harvest season for risk surface iii.

Niger food security 2009

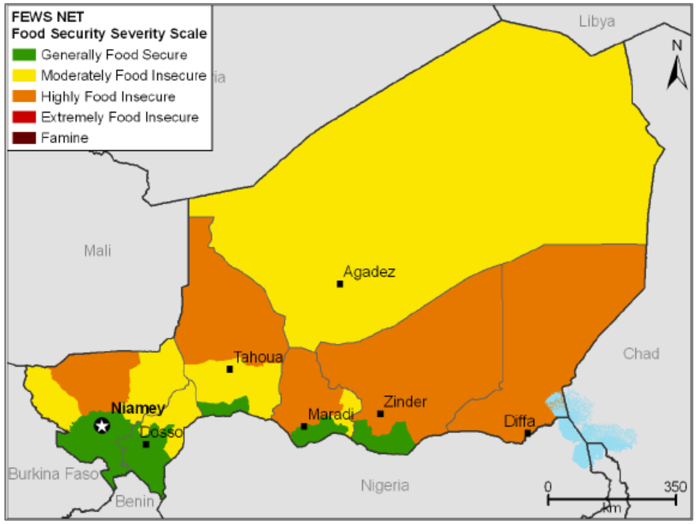


Figure 57 Food security assessment as of January 2010 (FEWS NET).

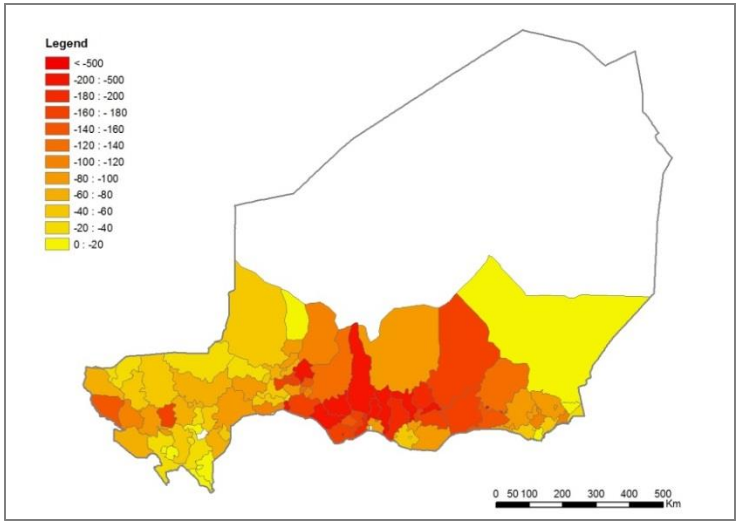


Figure 58 Model alert for 2009 harvest season for risk surface i.

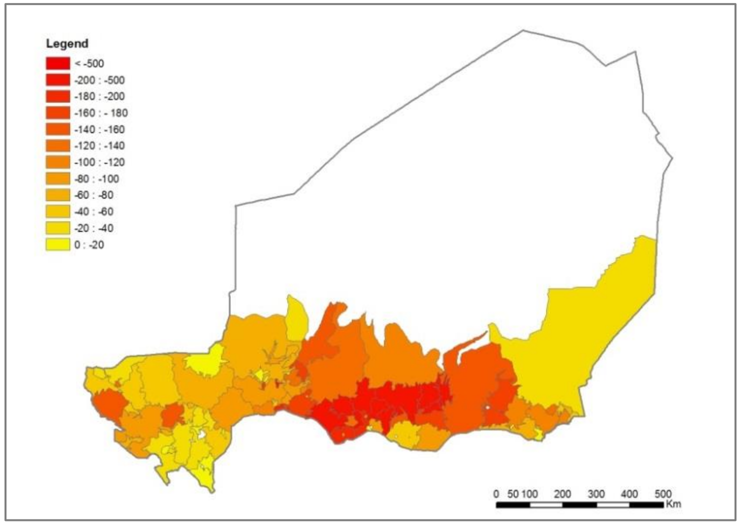


Figure 59 Model alert for 2009 harvest season for risk surface ii.

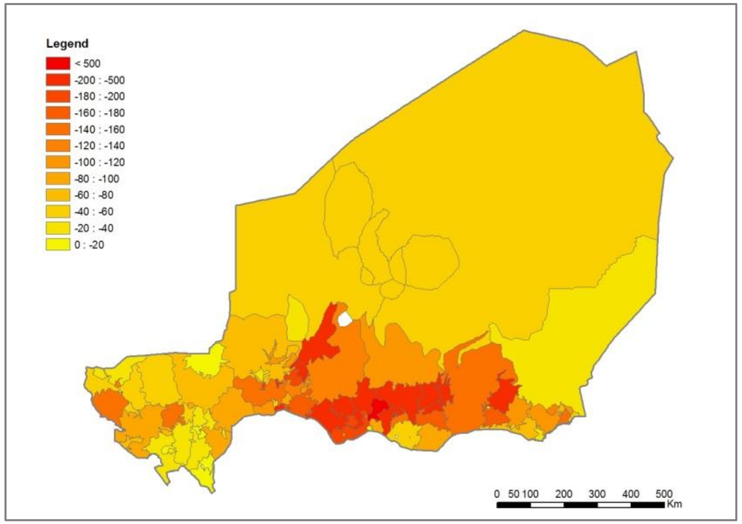


Figure 60 Model alert for 2009 harvest season for risk surface iii.

Niger food security 2010

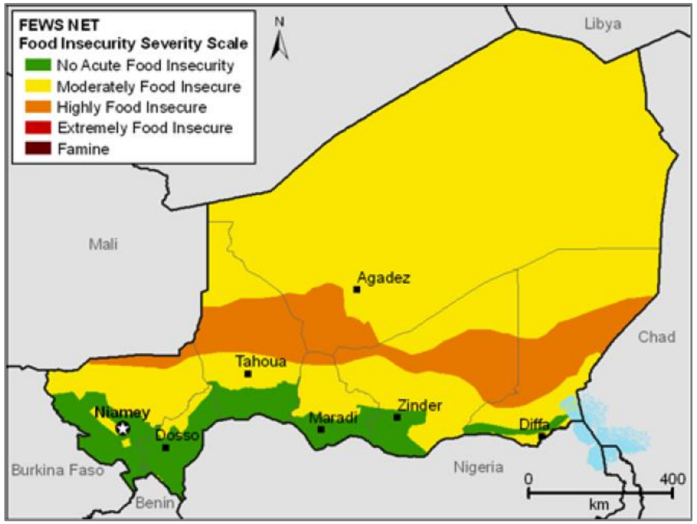


Figure 61 Food security assessment as of October 2010 (FEWS NET).

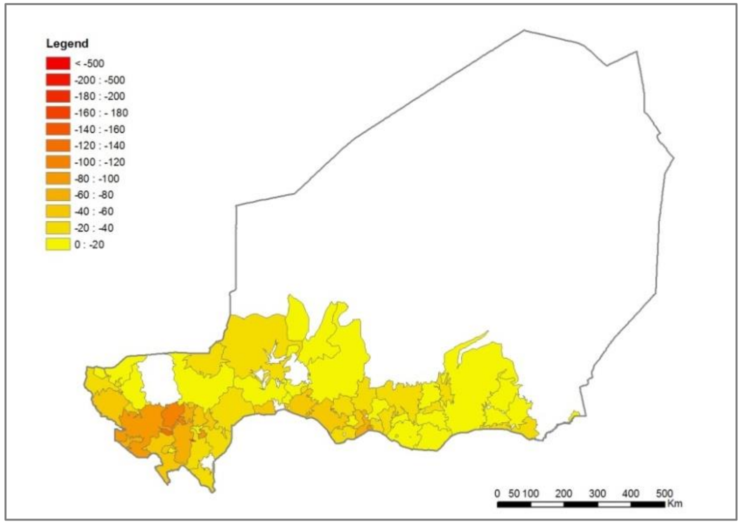


Figure 63 Model alert for 2010 harvest season for risk surface ii.

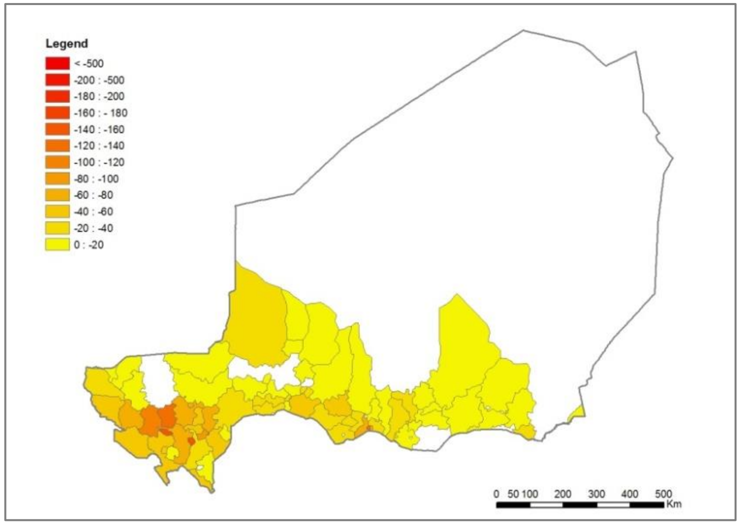


Figure 62 Model alert for 2010 harvest season for risk surface i.

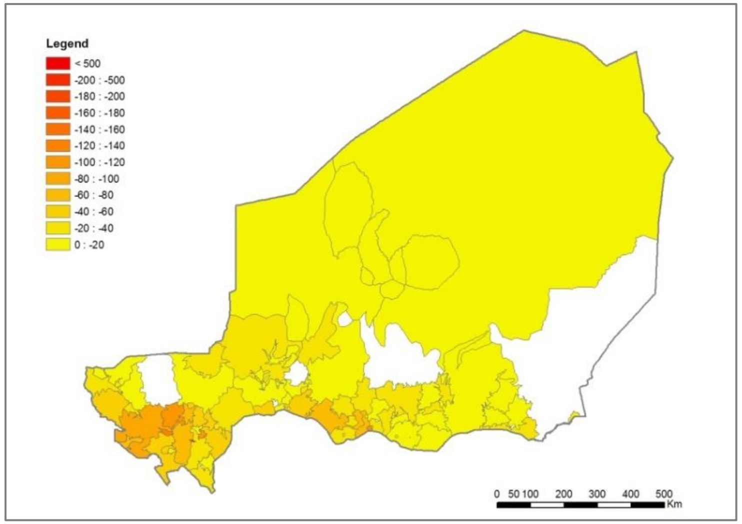


Figure 64 Model alert for 2010 harvest season for risk surface iii.

Niger food security 2011

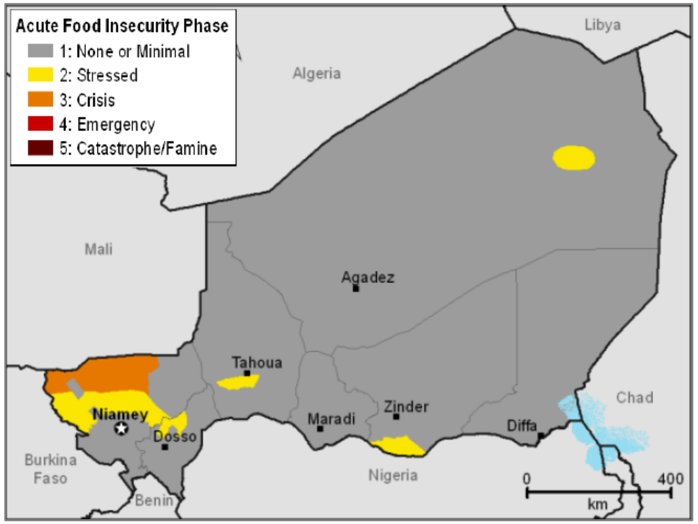


Figure 65 Food security assessment as of Sept. 2011 (FEWS NET).

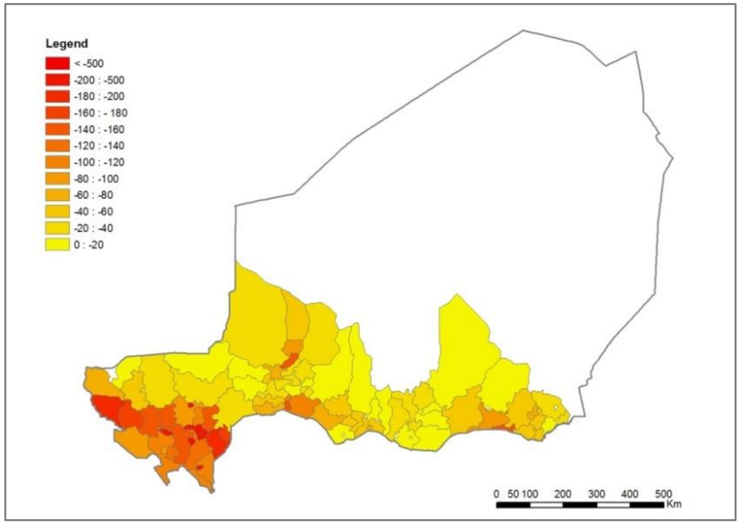


Figure 66 Model alert for 2011 harvest season for risk surface i.

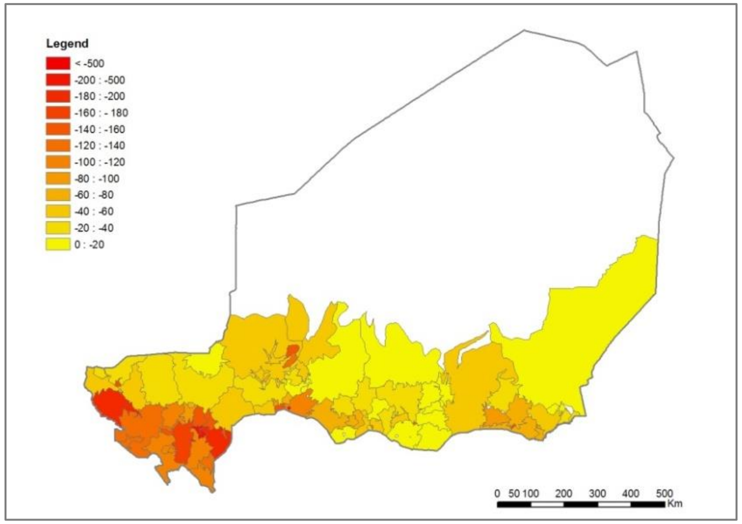


Figure 67 Model alert for 2011 harvest season for risk surface ii.

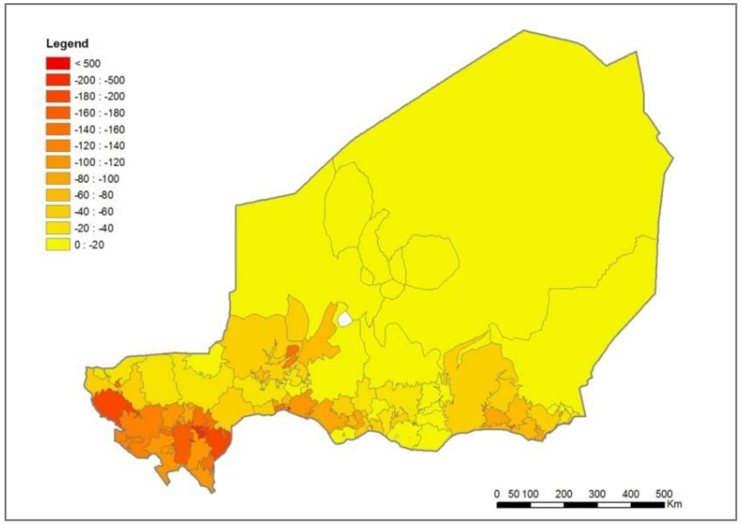


Figure 68 Model alert for 2011 harvest season for risk surface iii.

Niger food security 2012

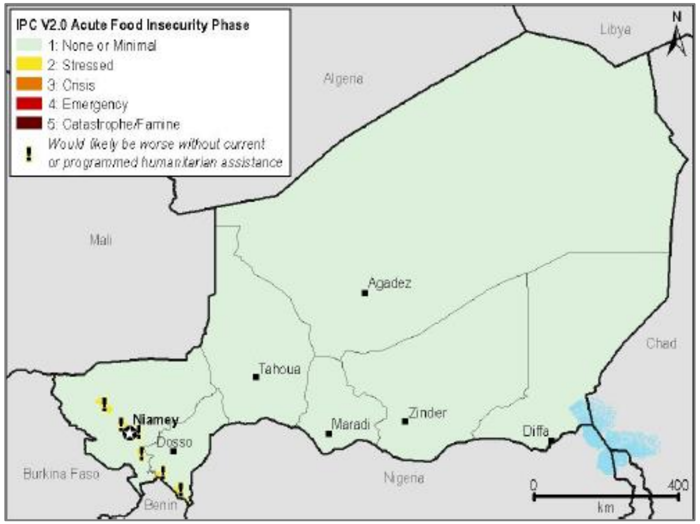


Figure 69 Food security assessment as of October 2012 (FEWS NET).

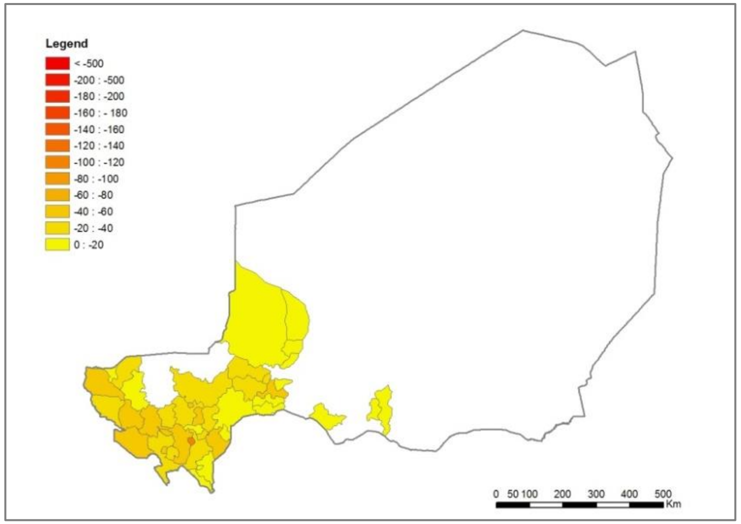


Figure 70 Model alert for 2012 harvest season for risk surface i.

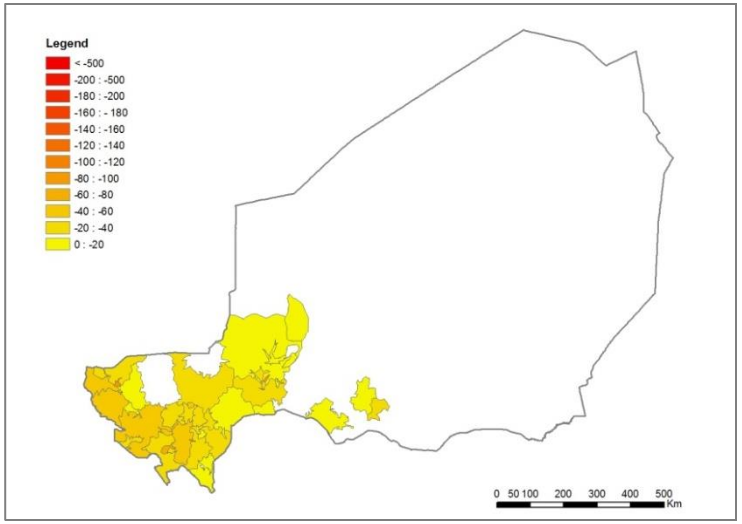


Figure 71 Model alert for 2012 harvest season for risk surface ii.

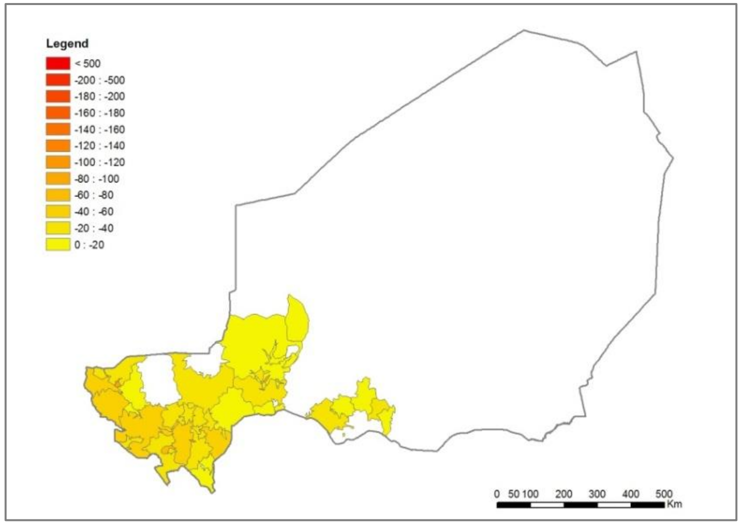


Figure 72 Model alert for 2012 harvest season for risk surface iii.

Niger food security 2013

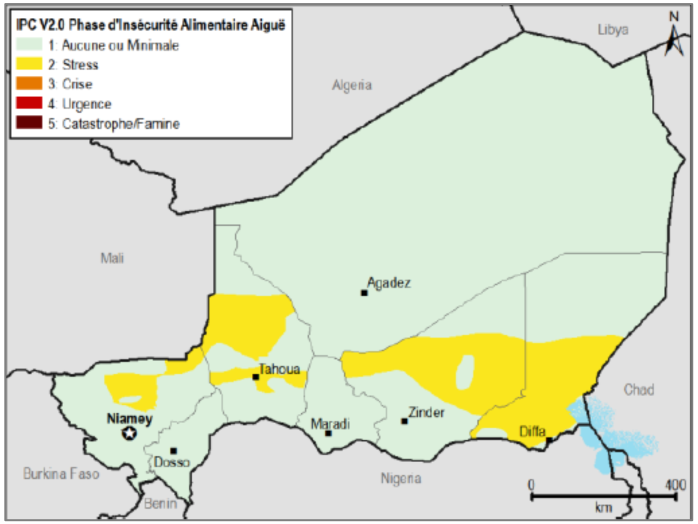


Figure 73 Food security assessment as of January 2014 (FEWS NET).

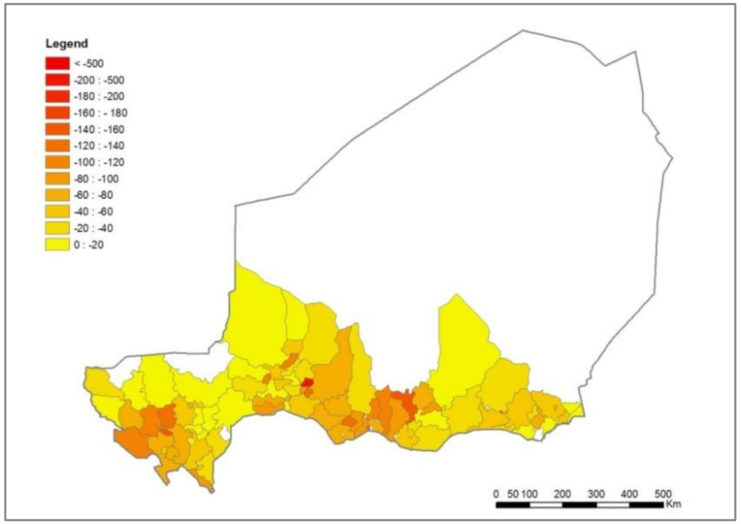


Figure 74 Model alert for 2013 harvest season for risk surface i.

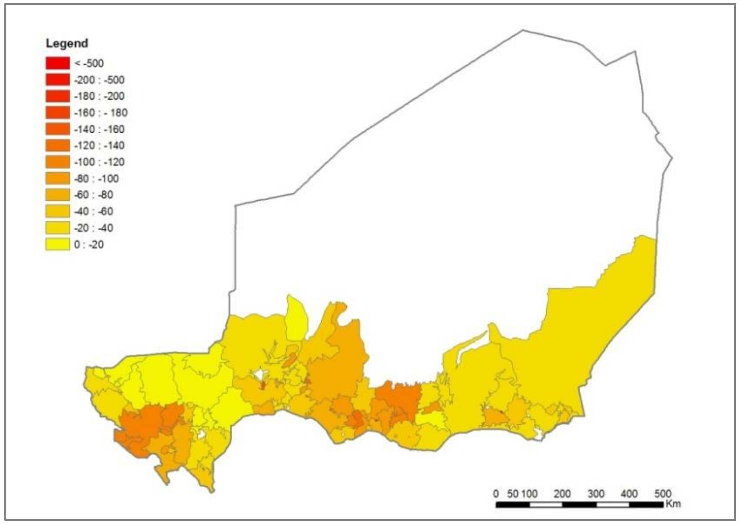


Figure 75 Model alert for 2013 harvest season for risk surface ii.

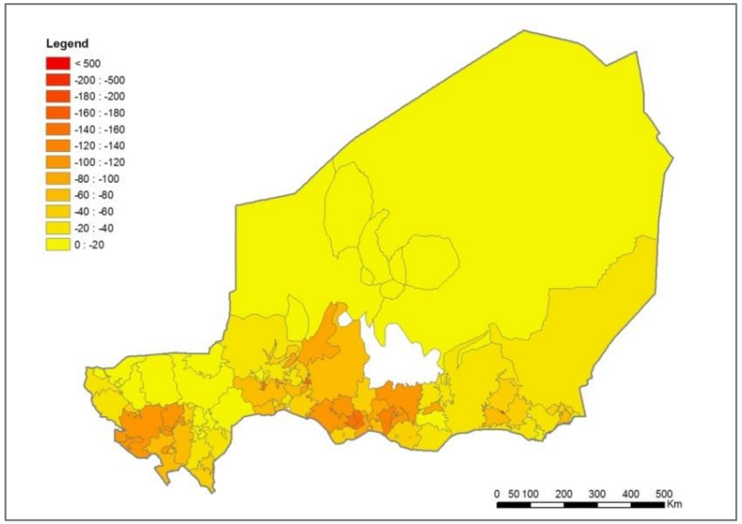


Figure 76 Model alert for 2013 harvest season for risk surface iii.

Mozambique food security 2008

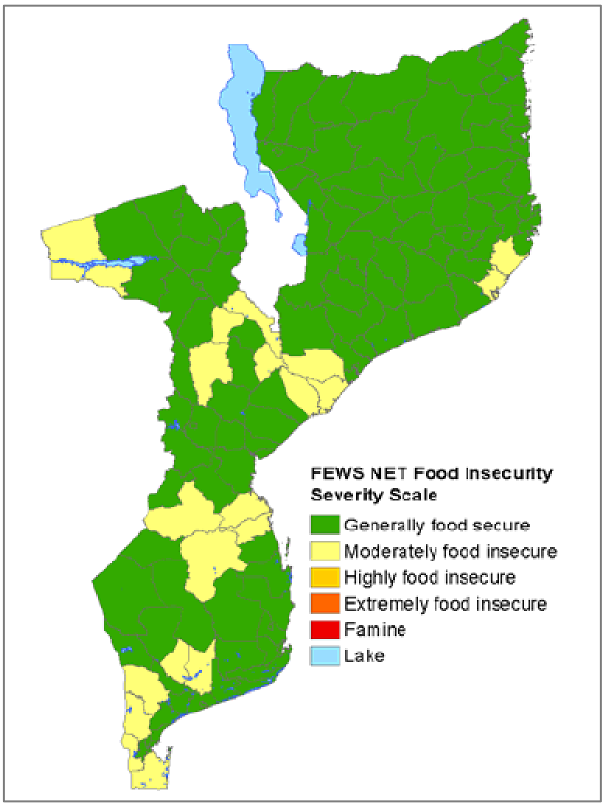


Figure 77 Food security assessment as of August 2008 (FEWS NET).

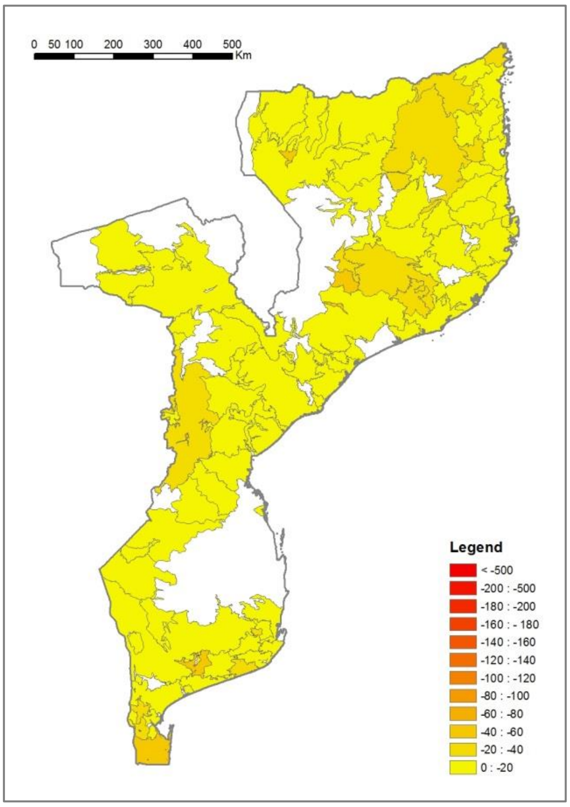


Figure 79 Model alert for 2008 harvest season for risk surface ii.

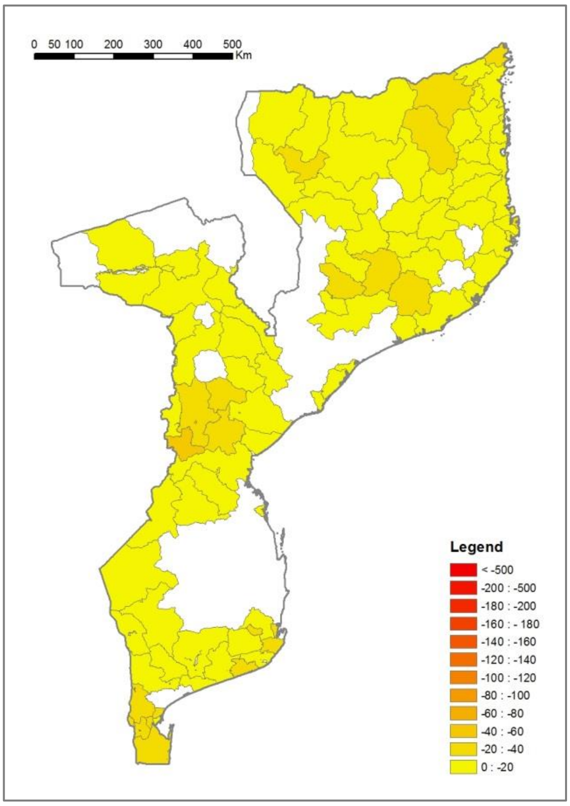


Figure 78 Model alert for 2008 harvest season for risk surface i.

Mozambique food security 2009

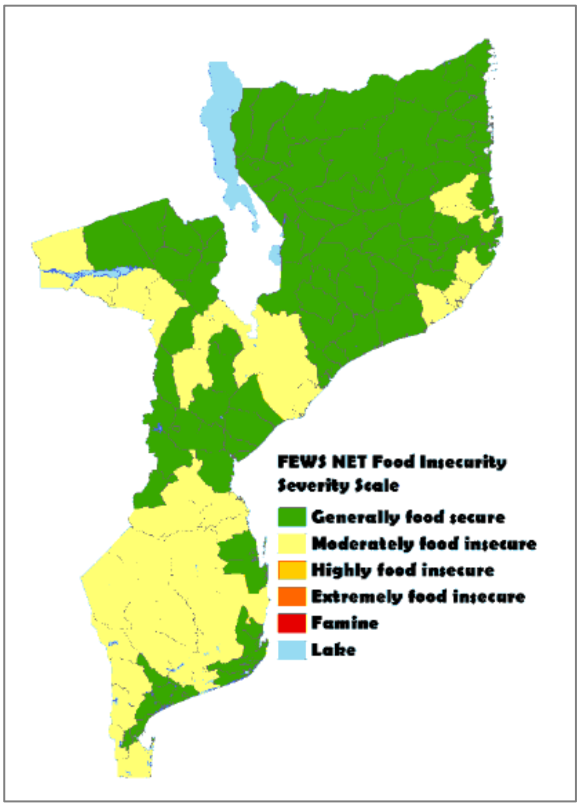


Figure 80 Food security assessment as of March 2009 (FEWS NET).

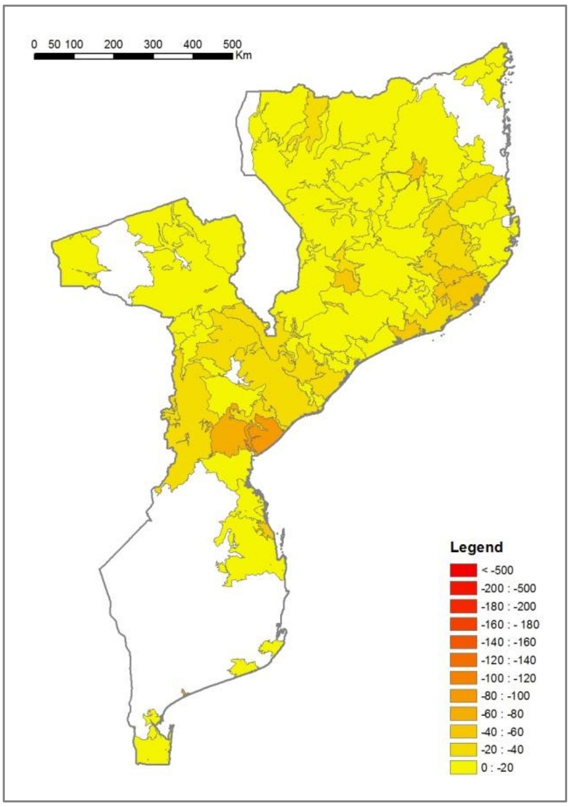


Figure 82 Model alert for 2009 harvest season for risk surface ii.

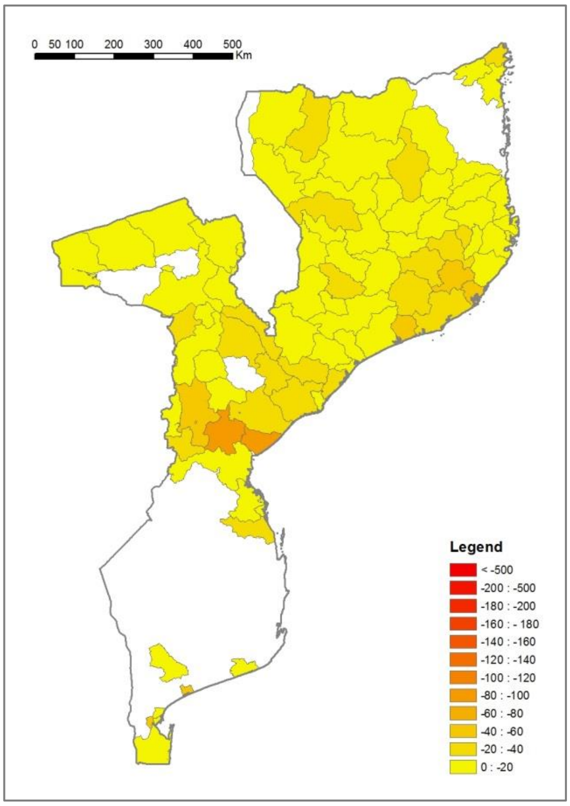


Figure 81 Model alert for 2009 harvest season for risk surface i.

Mozambique food security 2010

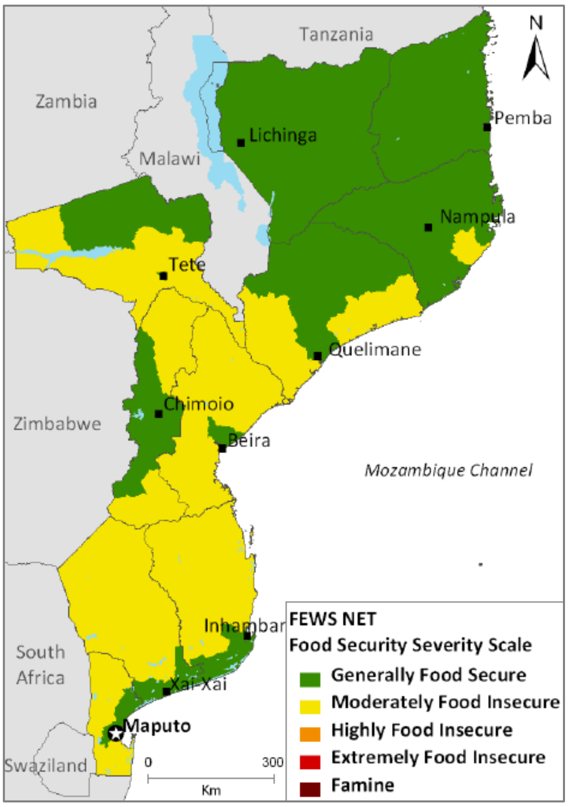


Figure 83 Food security assessment as of October 2010 (FEWS NET).

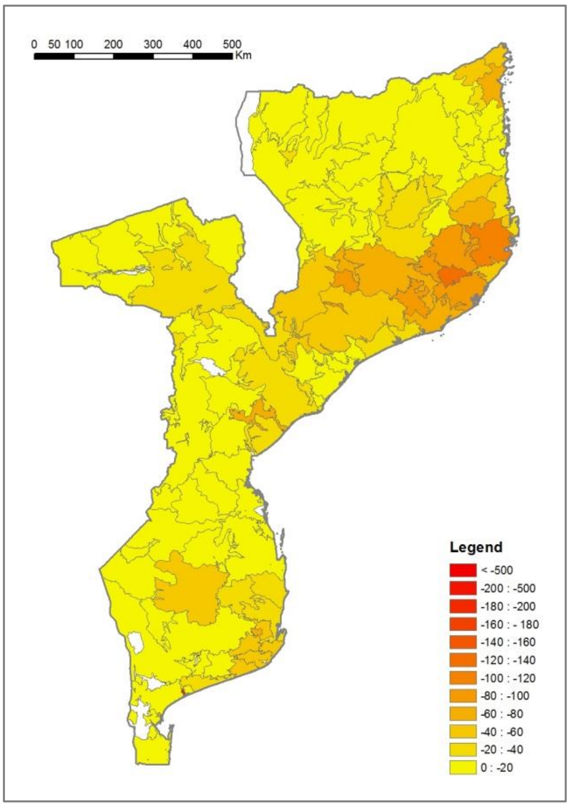


Figure 85 Model alert for 2010 harvest season for risk surface ii.

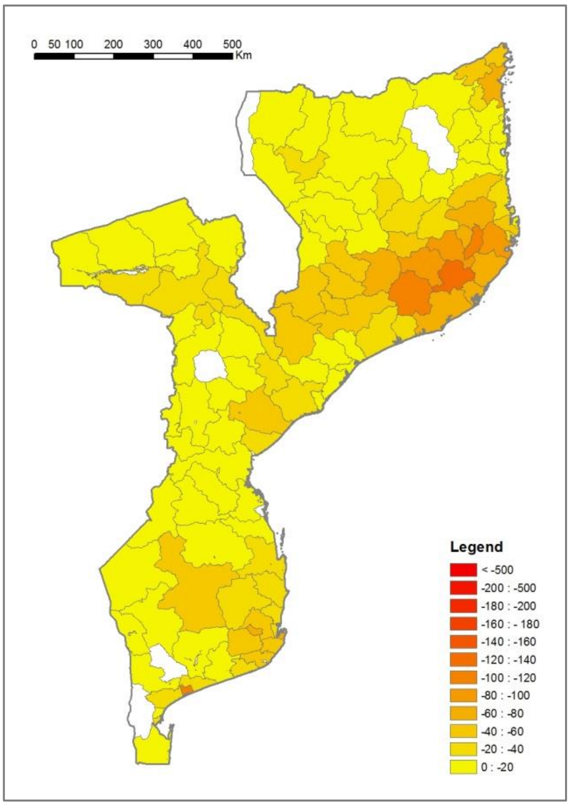


Figure 84 Model alert for 2010 harvest season for risk surface i.

Mozambique food security 2011

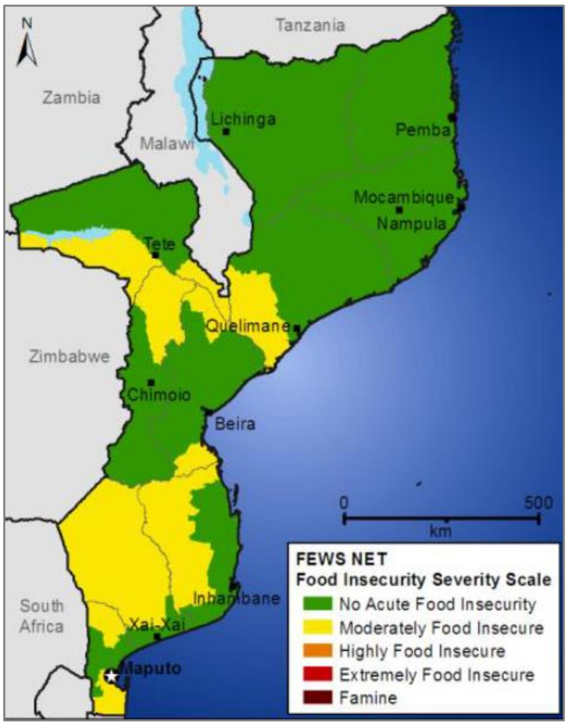


Figure 86 Food security assessment as of March 2011 (FEWS NET).

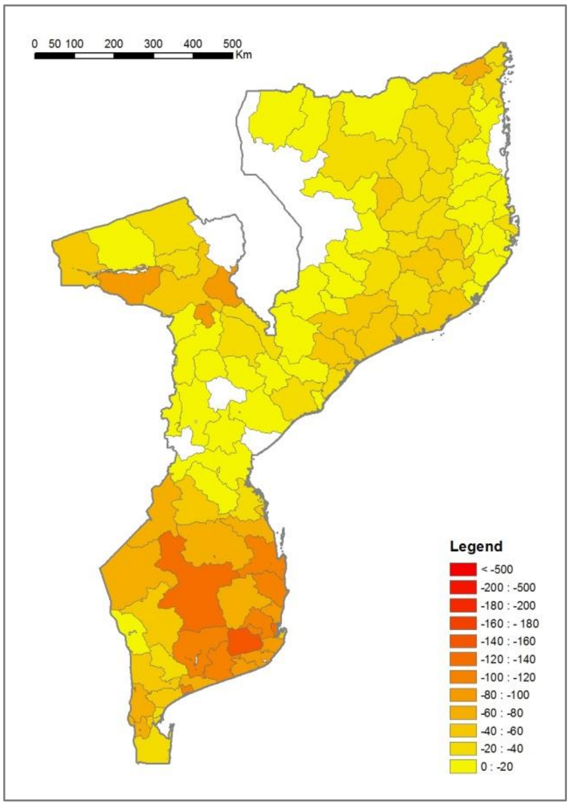


Figure 87 Model alert for 2011 harvest season for risk surface i.

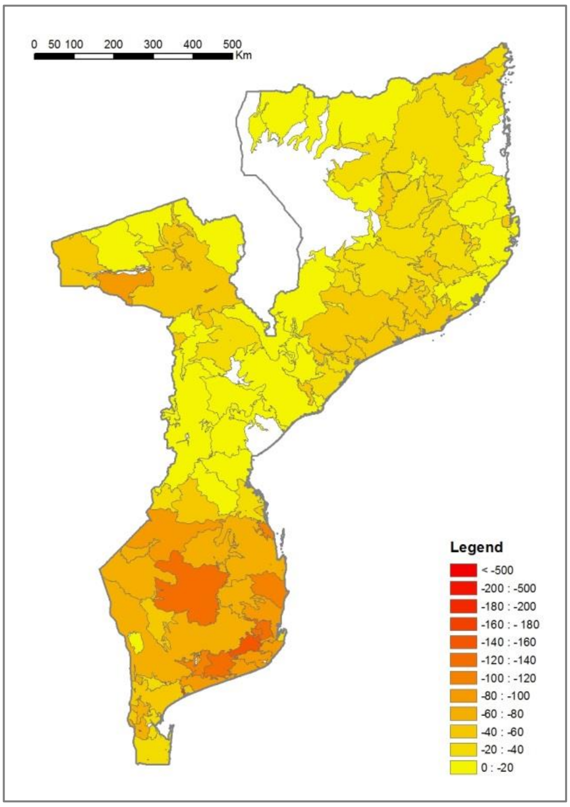


Figure 88 Model alert for 2011 harvest season for risk surface ii.

Mozambique food security 2012

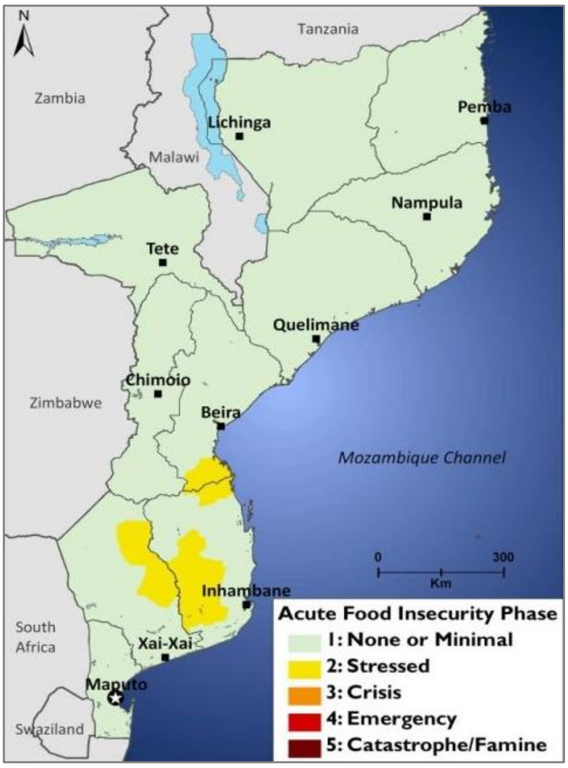


Figure 89 Food security assessment as of June 2012 (FEWS NET).

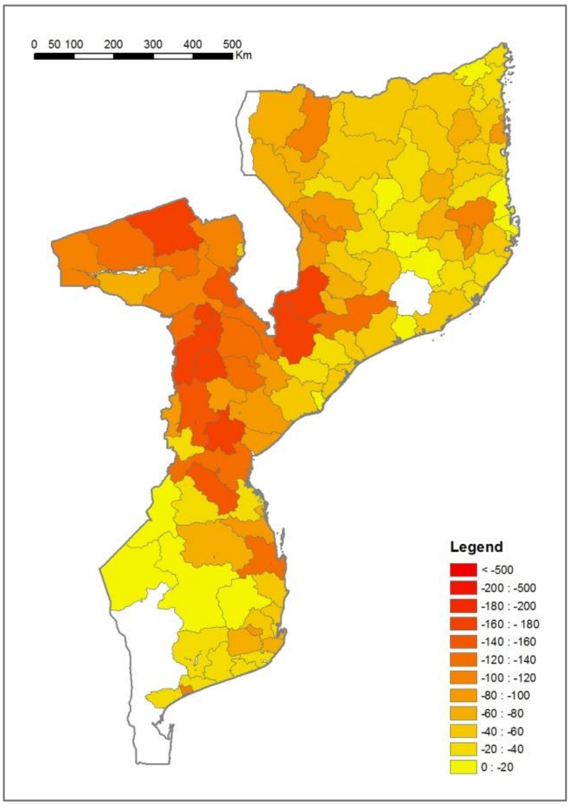


Figure 90 Model alert for 2012 harvest season for risk surface i.

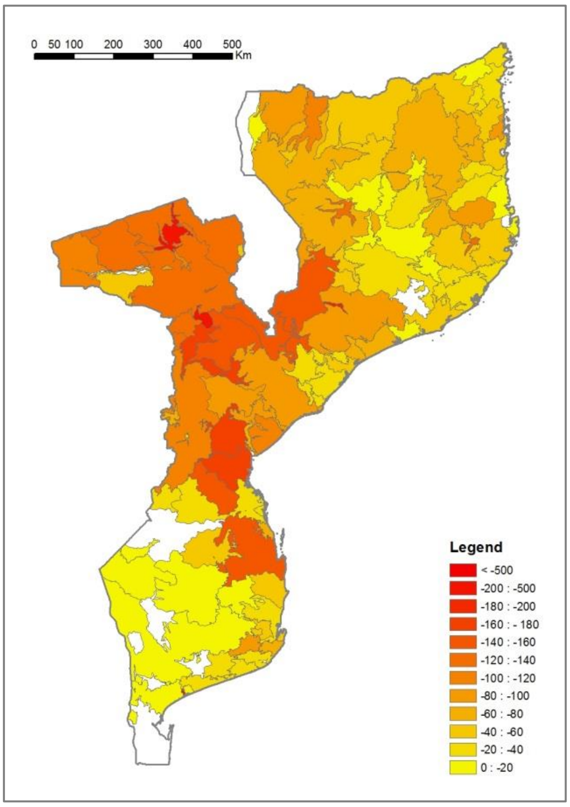


Figure 91 Model alert for 2012 harvest season for risk surface ii.

Mozambique food security 2013

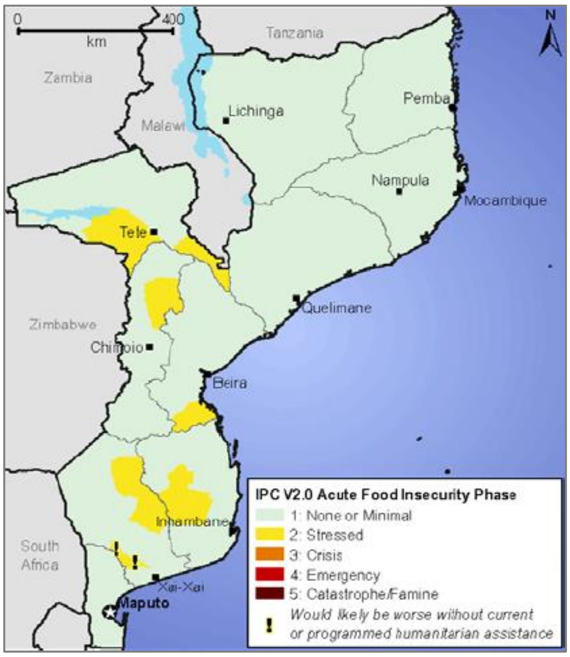


Figure 92 Food security assessment as of March 2013 (FEWS NET).

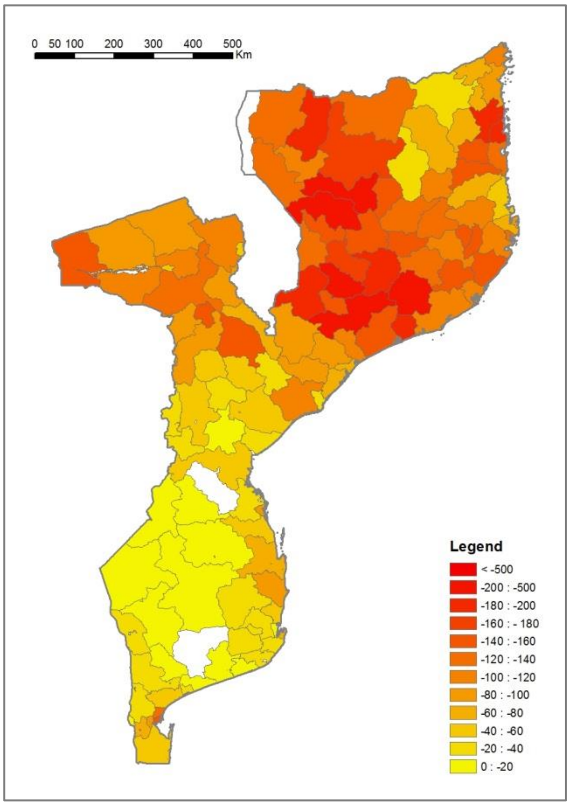


Figure 93 Model alert for 2013 harvest season for risk surface i.

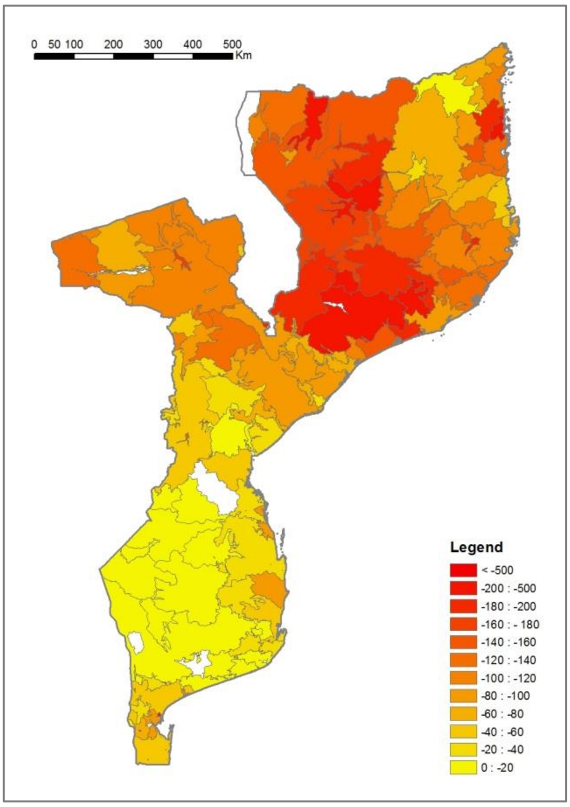


Figure 94 Model alert for 2013 harvest season for risk surface ii.

5.2 Quantitative evaluation

In order to perform a quantitative evaluation, by means of the use of FSA data (refer to paragraph 4.4.2 for more details about these data), it has been necessary to recalculate the average model alert values per administrative level 2. In fact the alert values produced by the model are given per risk surface units which don't correspond with the administrative boundaries (Figure 95). This operation was performed mainly with the Tabulate Intersection tool, which is available in the Geoprocessing toolbox of ArcGis (i.e. the tool computes the intersection between two feature classes and cross-tabulates the area of, length of, or count the intersecting features).

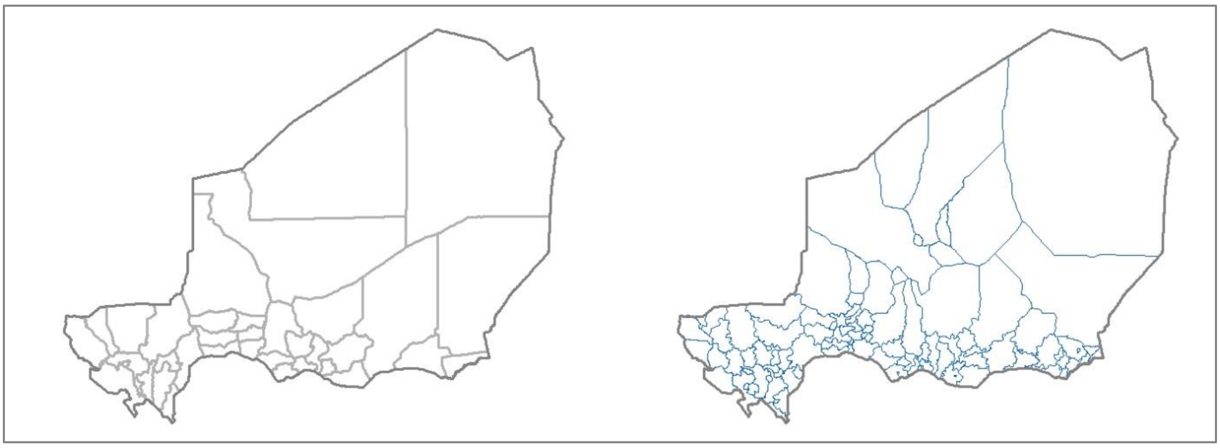


Figure 95 On the left the administrative level 2 of Niger, on the right the risk surface i calculated for Niger.

After the recalculation of the model alerts according to the administrative level 2 subdivisions, both FSA and final alert time series were then standardized over the available time series in order to make them comparable. What have been analyzed, and discussed in the following paragraphs, are not the single yearly values of the two datasets compared but their variations from one year to the next. As a matter of fact the absolute values of the final alert produced are considered so far less important than the correct interpretation of crisis within the proposed model.

A selection of the evaluation results of the model applied to the three type of risk surfaces is presented in the following, aggregated per department and per year, in order to provide an overview of cases in which the model worked properly and less well.

For the three risk surfaces the departments showing the best and worst results are presented, the graphs representing the comparison between FSA and model alert standardized values are reported from Figure 96 to Figure 103.

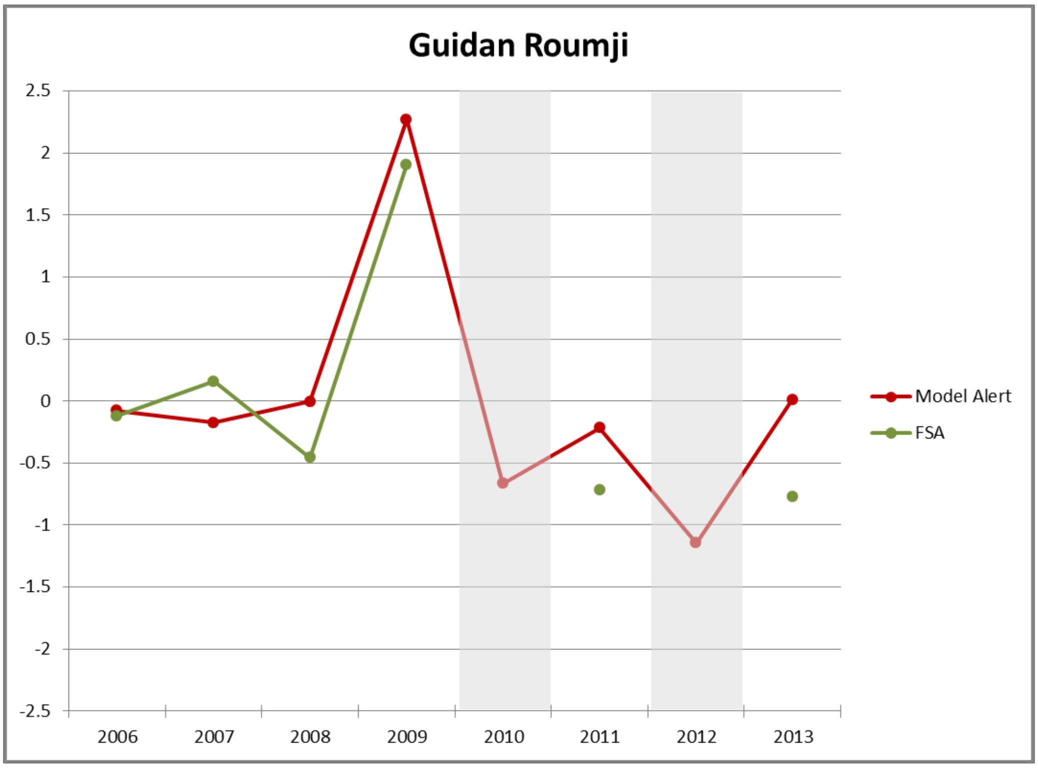


Figure 96 Validation for risk surface i for Guidan Roumji department. Values are standardized. Missing FSA values are highlighted in light grey.

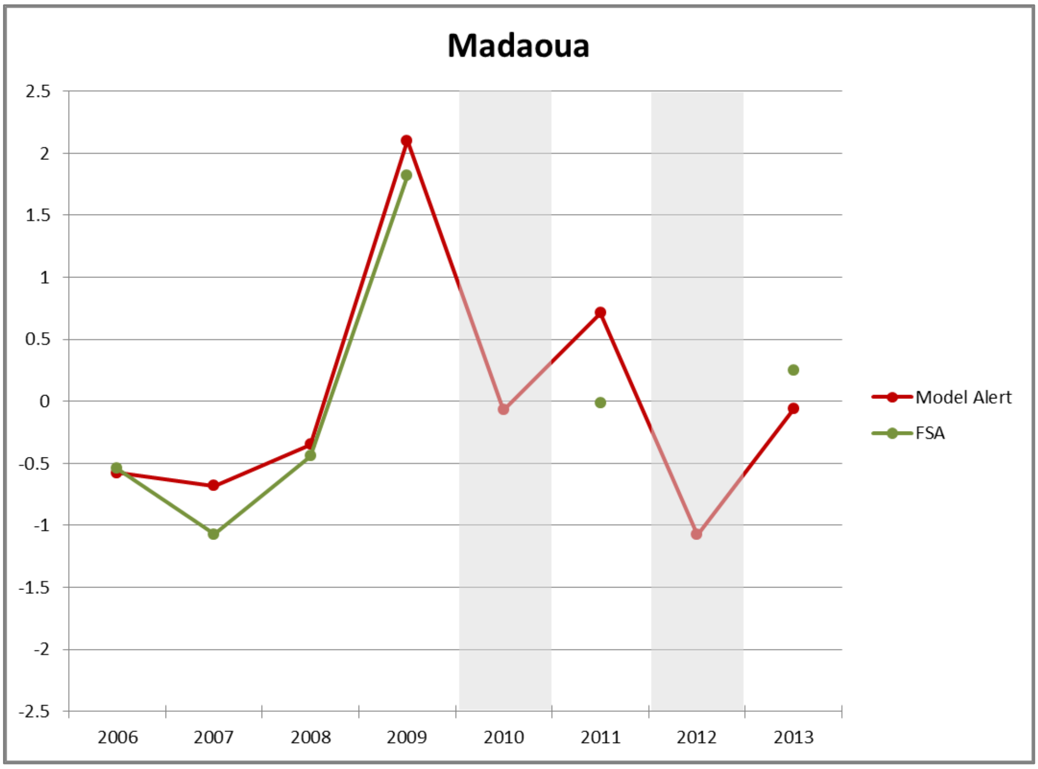


Figure 97 Validation for risk surface i for Madaoua department. Values are standardized. Missing FSA values are highlighted in light grey.

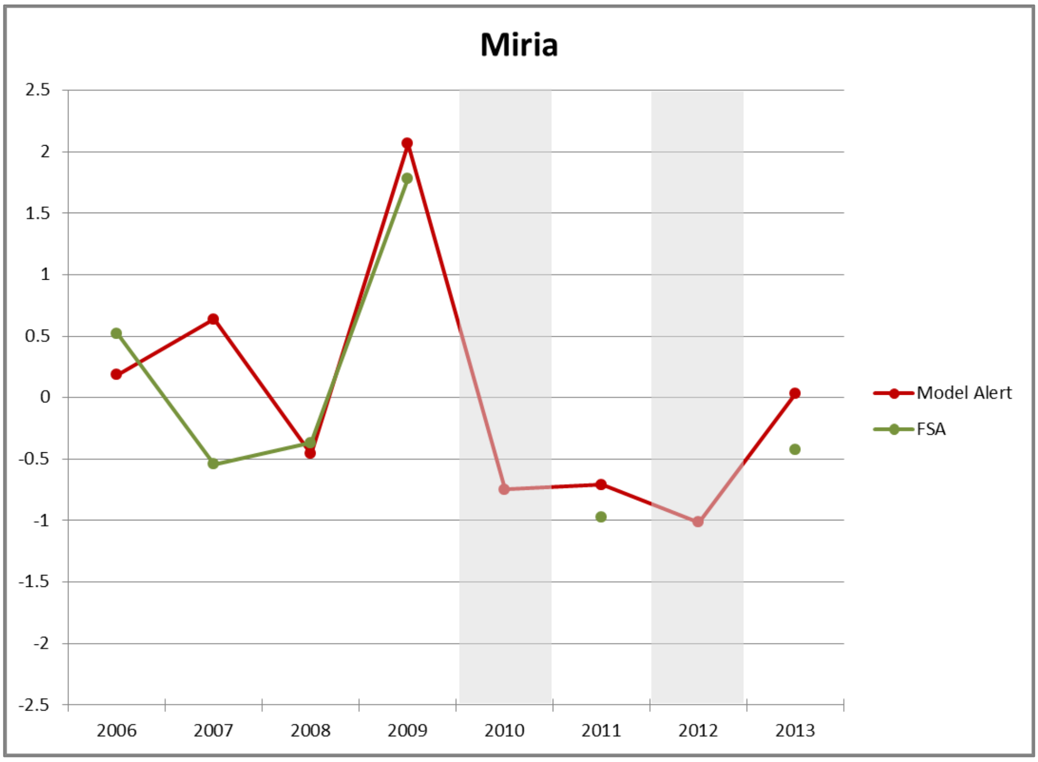


Figure 98 Validation for risk surface ii for Miria department. Values are standardized. Missing FSA values are highlighted in light grey.

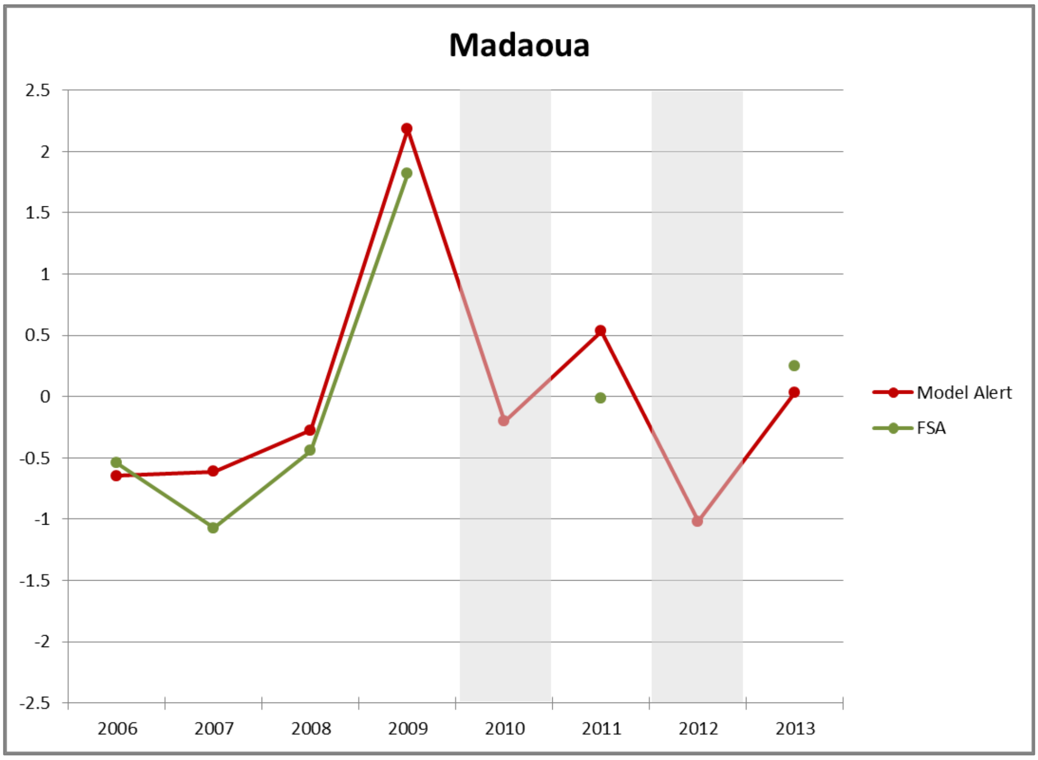


Figure 99 Validation for risk surface ii for Madaoua department. Values are standardized. Missing FSA values are highlighted in light grey.

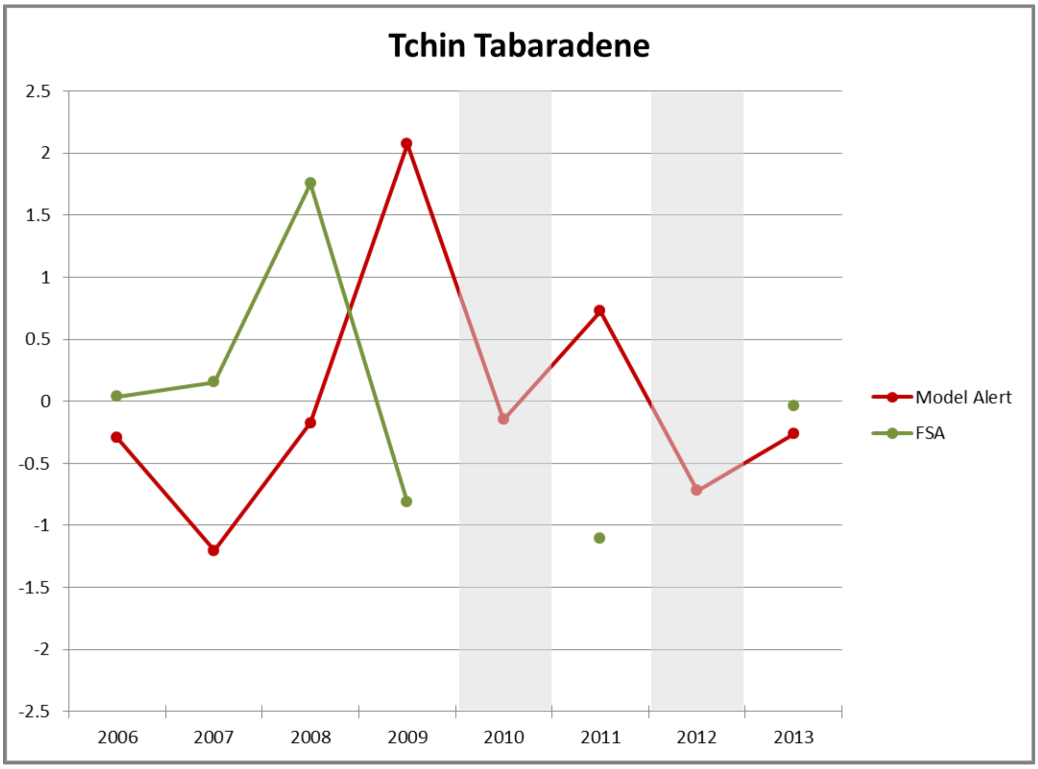


Figure 100 Validation for risk surface i for Tchin Tabaradene department. Values are standardized. Missing FSA values are highlighted in light grey.

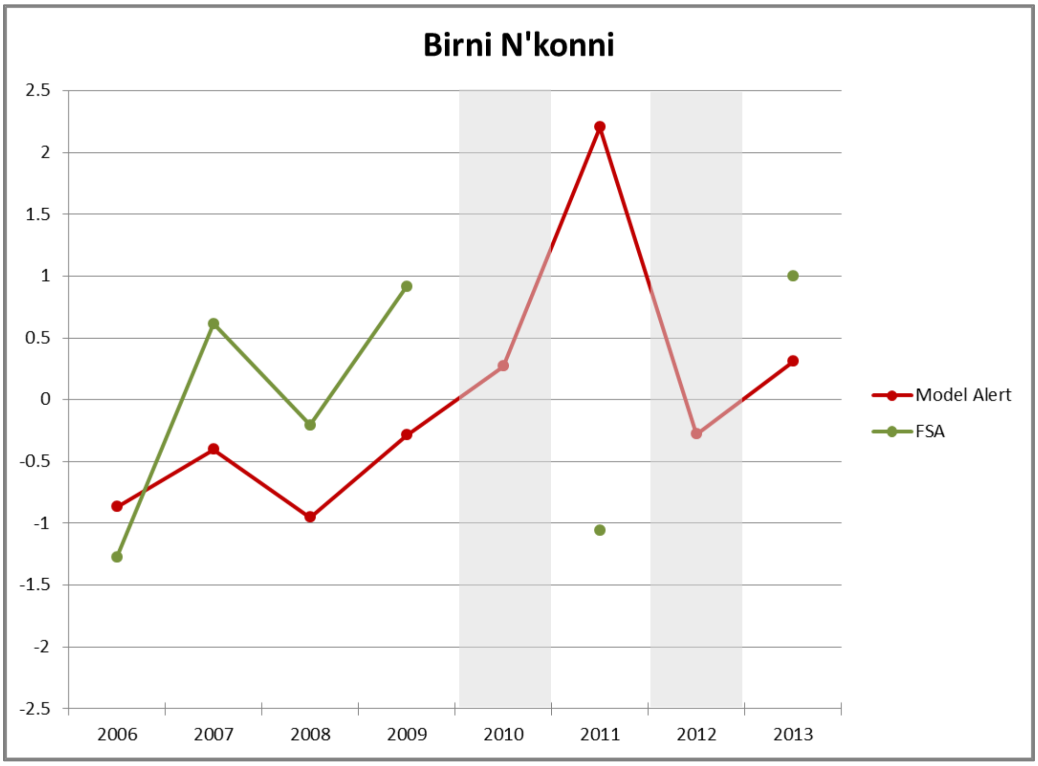


Figure 101 Validation for risk surface i for Birni N'konni department. Values are standardized. Missing FSA values are highlighted in light grey.

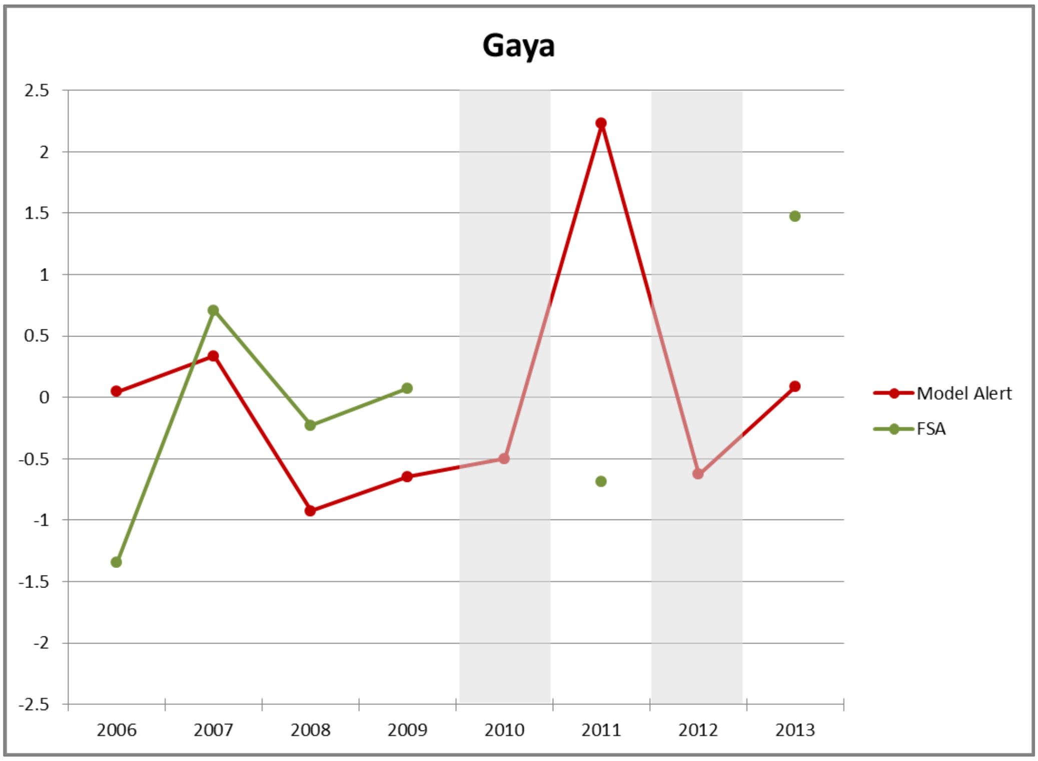


Figure 102 Validation for risk surface ii for Gaya departement. Values are standardized. Missing FSA values are highlighted in light grey.

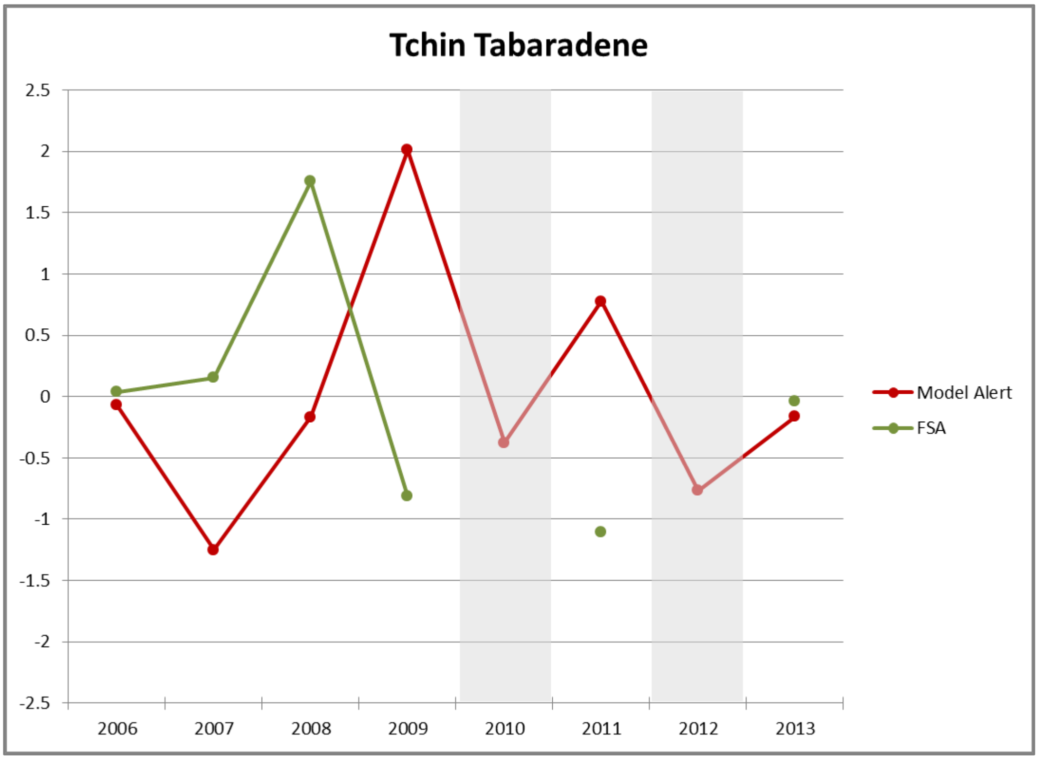


Figure 103 Validation for risk surface ii for Tchin Tabaradene departement. Values are standardized. Missing FSA values are highlighted in light grey.

In order to provide an overview of the results, the differences between values of the model alerts and of the FSA, already standardized, were calculated. The results are presented (Figure 104 and Figure 105) per each department as the average of the differences calculated over the time series 2006-2013. In order to better evaluate the model alerts it has been decided to recalculate those alerts by applying the agricultural vulnerability to the considered hazard and aggregating the results per administrative level 2 (departments). This was done in order to evaluate the significance of the three proposed risk surfaces through the comparison of original final alerts with those obtained by using the model without any of the risk surfaces; results are shown in Figure 106.

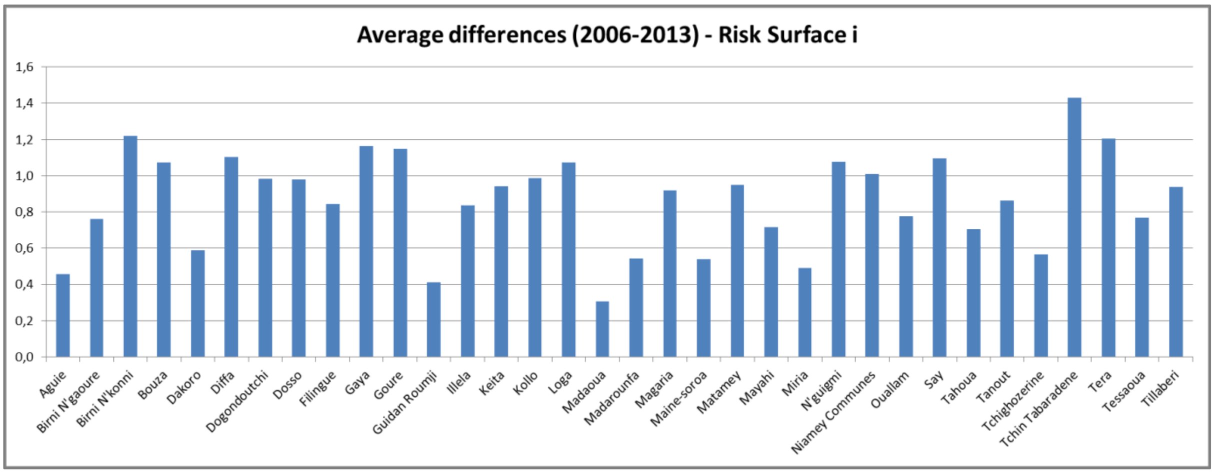


Figure 104 The graph presents the mean of the differences between the Model Alerts (Risk surface i) and the FSA calculated over the period 2006-2013 per department.

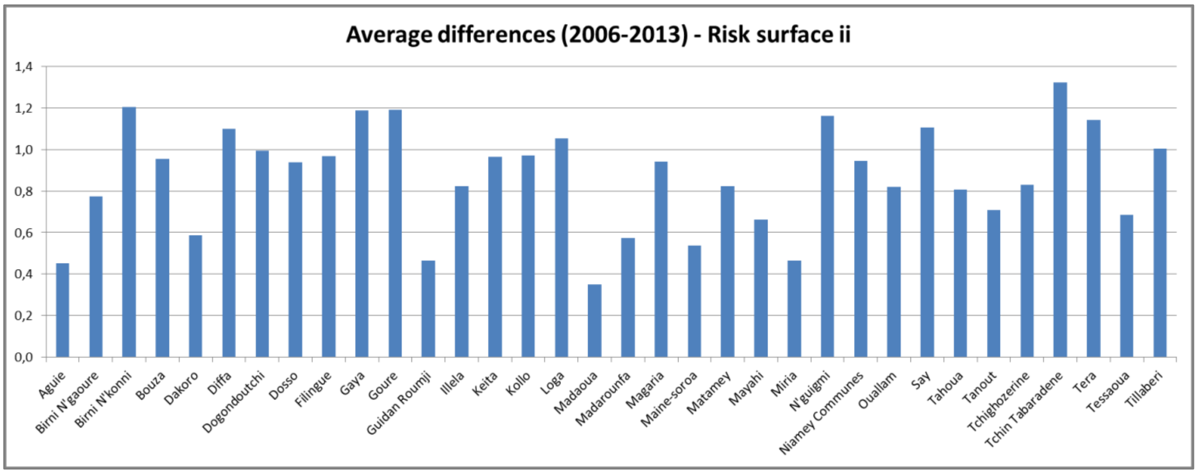


Figure 105 The graph presents the mean of the differences between the Model Alerts (Risk surface ii) and the FSA calculated over the period 2006-2013 per department.

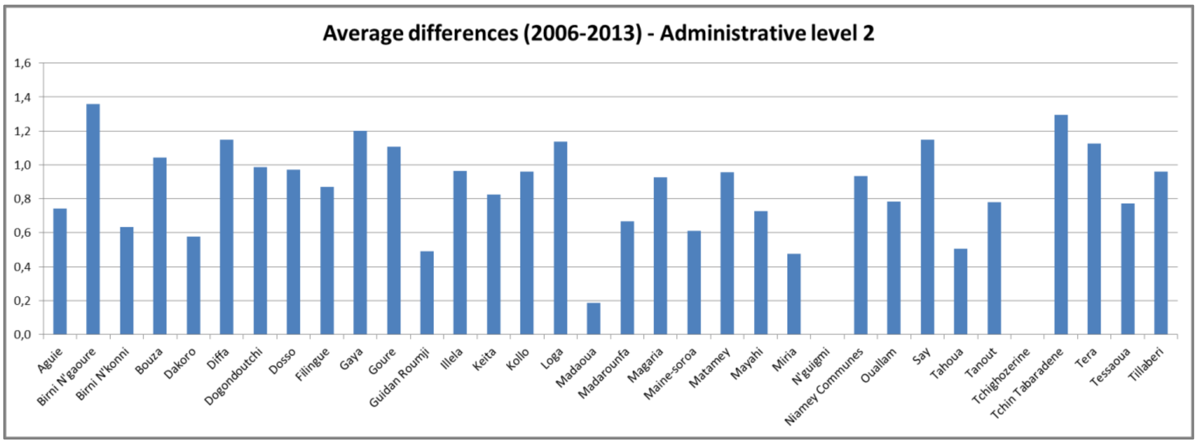


Figure 106 The graph presents the mean of the differences between the Model Alerts (Administrative level 2) and the FSA calculated over the period 2006-2013 per department.

5.3 Discussion

In this paragraph results of both qualitative and quantitative evaluation are discussed.

Qualitative evaluation

The following considerations are to be made with respect to the qualitative truth data used (i.e. Fews Net assessments and outlooks): these data, as well as the FSA data used for the quantitative evaluation, reflect the food security actual or projected status by analyzing a set of indicators, among which the trend of the crop production season is surely an important one but not the only one. The main difference between the model alerts and the Fews Net products are then to be identified in the fact that the first accounts mainly for agricultural drought conditions, while the second accounts for a variety of hazards that the ITHACA early warning system itself is not able to, nor designed for, detect. In particular ITHACA EWS is conceived to monitor vegetation conditions on the basis of phenological parameters obtained through satellite-derived NDVI data. Other hazards that quite frequently hit the countries being analyzed are: floods, plant pests and human conflicts. In addition, the food security of vulnerable households is highly influenced by their purchase power; in the last decade variations of prices of staple food decided in international commodity exchanges have highly negatively affected the possibility of farmers of developing countries to sell and buy crops at affordable prices. For instance the global maize price spike of 2008[34] was largely determined by the diversion of crops (maize in particular) for making first-generation biofuels (Mitchell, 2008); in that occasion the prices rose without apparent motivation in countries in which this commodity is one of the daily food pillars. The repercussions of food price rise are noticeable worldwide but when developing countries are considered the effects can't be absorbed by farmers' capacity to adapt to global market changes, which is very limited. The model herein presented does not integrate the analysis of price movements, both local and global, while Fews Net methodology does, therefore the two compared products are expected to diverge for this reason too.

In spite of the just mentioned issues, it must be pointed out that truth data targeting food security status are rare and inhomogeneous; therefore an evaluation with the proposed truth data was considered a fair compromise in order to perform an evaluation, even broad, that is too often bypassed when developing EW systems.

In the first place it can be stated that the presented model gives, in general and not distinguishing among country regions, higher and more extended alert levels compared to Fews Net products; this is generally true both for years of acknowledged food security crisis and for years of none or minimal crisis. This can be due to the fact that being the model hazard derived only from environmental assessments (i.e. Seasonal Small Integral derived by NDVI analysis) it can't take into account the existence of food stock and of above average food production in the precedent year; these two conditions are liable to

[34] http://www.fao.org/worldfoodsituation/foodpricesindex/en/

increase the food security level of households. Another possible explanation, valid in particular for the case of Mozambique, is that very short growing seasons (e.g. lasting one or two months) are not detected by ITHACA vegetation anomaly monitoring system. It happens that the seasonal crop calendar for Mozambique (see Figure 42) is characterized by two planting and harvesting seasons in the southern regions of the country. This could cause the inconsistency of the model alerts with respect to the Fews Net assessment, as the latter takes into account the whole yearly production and not the one produced during the only main crop season. It should also be pointed out that no threshold value is fixed on the alerts retrieved by ITHACA vegetation anomaly monitoring system, thus all the anomalies detected are categorized and reported in the output products. An analysis of further case studies would permit to identify a threshold value in order to distinguish between false alerts (i.e. small values to be considered negligible) and true ones.

Secondarily if one considers years 2008, 2009 and 2010 (from Figure 53 to Figure 64) some considerations can be made about the differences in the functioning of the model with respect to the three type of risk surfaces tested on the Niger case study: the model using **risk surface i** provides good outputs for the southern regions of the country, so it does the model using **risk surface ii**, whilst both the models fail to provide alerts over the northern regions. Southern regions (in particular the south-eastern ones) are those characterized by the major presence of cultivated land so as to be called the wheat belt (*le grenier du Pays*, in french), while northern regions are characterized by the presence of the desert and thus of an environment unfitting to cultivations. Given the fact that the **agricultural vulnerability** surface is calculated only for those pixels identified as agricultural land and that all the further calculations are based on this primary distinction between cultivated and non-cultivated land, it is clear that the northern desert areas are almost never screened for food security alerts. However, in the case of the model using **risk surface iii**, the risk units of northern Niger are provided with an alert for each of the years that were considered in the analysis. In fact markets of the northern regions, such as Agadez, Arlit or Bilma (refer to Figure 38 for market location and to Figure 52 for administrative level 2 subdivisions), are evidently supplied by the southern markets located in food production surplus areas. The latter is confirmed by the analysis of the local market database in which the food trades data are stored and described (see Table 7). When building **risk surface iii** the interrelations among markets were considered, therefore part of the staple production drop that occurs in the wheat belt is reflected in the northern regions, which are not autonomous with respect to food production.

The latter consideration proves the model to be useful when a specific country is analyzed. However the application of a country-tailored vulnerability model based on local market network information would be difficult to be implemented at global extent, which is the target extent of the ITHACA EWS for drought.

Quantitative evaluation

The results of the quantitative evaluation are highly variable from one department to another and from one year to another as well. The generic considerations (i.e. short available time-series, evaluation data not drought specific) made for the data used for the qualitative evaluation are valid for the FSA evaluation data as well; they could be the main factors leading the differences revealed by the comparison. However it must be remembered that quantitative data regarding food security conditions are rarely produced and made available; this is the reason why FSA data were nevertheless used for evaluative purposes.

Firstly it must be pointed out that the performances of the model which uses the **risk surface i** and those of the model using the **risk surface ii** don't differ significantly. One of the reason can be found in the fact that the two risk surfaces are geographically similar because the basic choice of importance factors inserted in the gravity spatial model (i.e. 3, 2, 1 values assigned to wholesale, assembly and retail markets respectively), used to build the **risk surface ii**, was the only tested option. The case of the model which uses the **risk surface iii** would reasonably give rather different results, however it was decided not to evaluate them considering that the assumptions made to build this risk surface iii were quite arbitrary and primarily needed in order to test the option but are not considered valuable from the quantitative point of view.

The results of the evaluation process for the departments of Madaoua and Guidan Roumji, obtained with the **risk surface i**, show good correspondences between the two data series (see Figure 96 and Figure 106). However it appears that 2007, 2011 and 2013 are the years for which the model alerts differ more from the FSA data. Madaoua department shows the best results among the others also when the model using the **risk surface ii** is considered (see Figure 99). A good performance was proven also for the Miria department in this second case (see Figure 98). The same three years affect negatively the overall results of the model that uses the **risk surface ii** as well. If one analyses the hazard occurrences for those years, it finds no particular causes that could have affected the food security in the country. It can be eventually said that these three departments (i.e. Miria, Guidan Roumji, Madaoua) are located in the southern part of the country where most of the croplands is, this fact could explain the overall good performance of the model in the area.

The model, both when using **risk surface i** and **risk surface ii**, provides controversial results for the following departments: Tchin Tabaradene, Birni N'konni and Gaya (see from Figure 100 to Figure 103). The model alerts differ considerably from the FSA data and in a comparable way for all years of the time series. As long as Tchin Tabaradene is concerned a possible explanation of the wrong alerts associated with this department is the fact that it is situated nearby the desert and thus the alerts provided by the model don't represent properly a land with none or minimal cropland (see Figure 107). For what concerns the departments of Birni N'konni and Gaya it is likely that, as they rely on markets close to the border with Benin and Nigeria, they are strongly influenced by the production of those countries and by the imports.

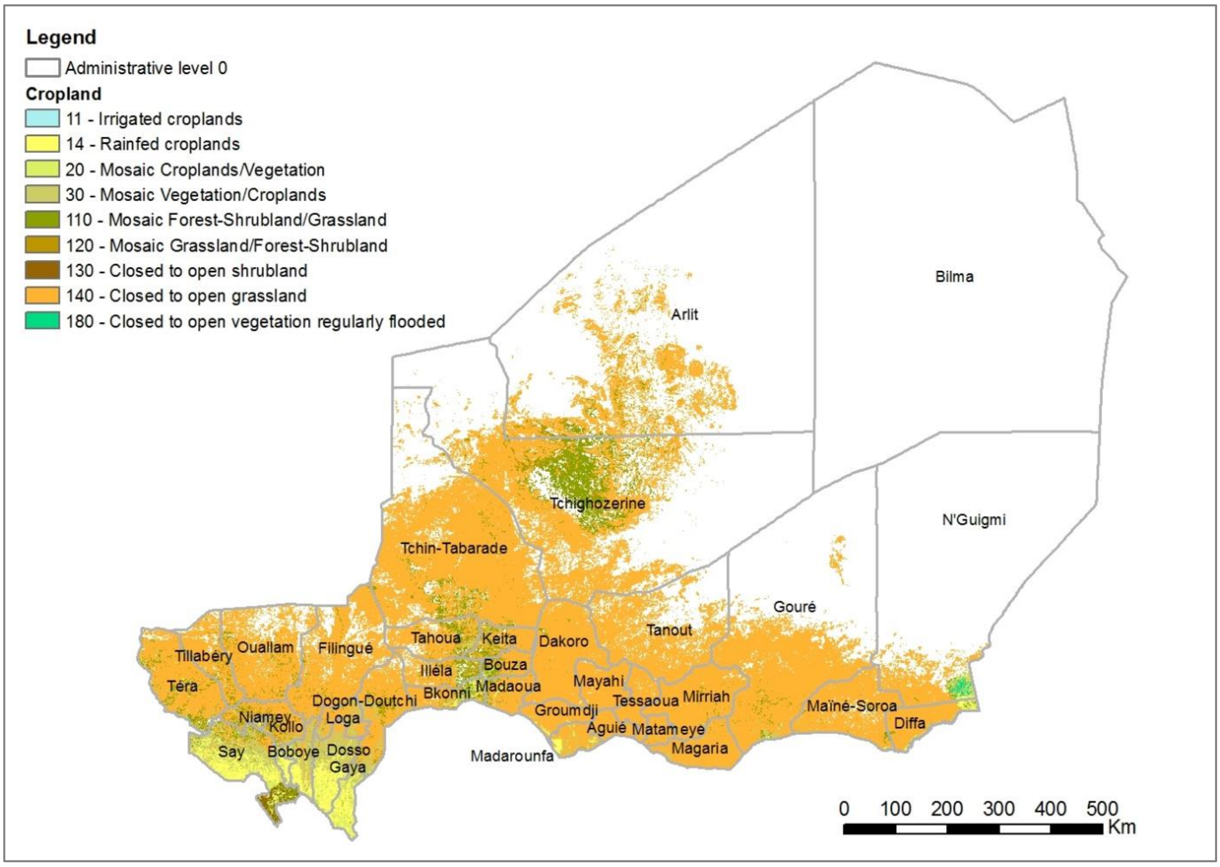


Figure 107 Map showing the identified cropland or cropland like (source: ESAGlobCover, 300 m resolution, © ESA 2010 and UCLouvain, © ESA / ESA GlobCover Project) and the administrative level 2 subdivision (GAUL, 2008) for Niger.

When the average differences are considered it can be seen that these are slightly amplified when the **risk surface i** is considered with respect to the **risk surface ii**, but in general the variations among one department and the other are very similar in the two cases. The average differences calculated for the final alerts obtained making the model run over departments in place of risk surfaces (Figure 106), are unexpectedly quite similar to that referring to the model alerts calculated with the risk surfaces (Figure 105 and Figure 106). Although it could seem that aggregating the weighted alerts per department gives substantially similar results, it must be pointed out that when no risk surfaces are being used the alerts aren't, in any case, detected for 4 out of the 36 departments (i.e. Arlit, Bilma, N'Guigmi and Tchigozerine). The latter is due to the fact that the departments are vaster than the risk surface units, thus the ratio alerted pixel to total cropland pixel is smaller for departments than it is for risk surfaces, engendering the underestimation of alerts in the first case. The usefulness of analyzing and subdividing the alerts into smaller units eventually depends by the desired level of detail of the analysis itself.

CONCLUSIONS AND FURTHER DEVELOPMENTS

The research targeted the complex aim of defining a vulnerability model to be integrated into an existing early warning system for drought. The need of integrating vulnerability for measuring risk towards natural hazards, especially in the case of drought, was stated both by international agencies dealing with disaster reduction (UN/ISDR, 2004a; UNDP, 2004) and by the scientific community (W. Neil Adger, 2006; S. L. Cutter, Boruff, & Shirley, 2003; Susan L. Cutter, 1996). It has also been authoritatively declared that the process for make the vulnerability information available and accessible to the profit of engineers, planners and policy-makers is in the current agenda of the international community working for the creation of disaster resilient societies (UN, 2006).

In order to build the model, existing system for drought risk assessment were investigated (Birkmann & Mucke, 2011; Peduzzi et al., 2009; Wilcox et al., n.d.), as well as recommendations for building indicators to assess people's vulnerability to droughts (Eriygama et al., 2009; Julich, 2006; Miller et al., 2002) were considered.

Starting from the hazard data provided by a specific drought monitoring system (i.e. NDVI-based seasonal vegetation anomalies calculated on a 5km grid) it has been decided to add to the system both agricultural specific and socio-economic vulnerability factors. The introduction of vulnerability factors has the objective of translating the environmental hazard into impacts on population. The change in food security conditions was targeted as the main indirect impact produced by drought conditions detected by the vegetation anomaly monitoring system.

The proposed vulnerability model is conceived as relying on two surfaces, i.e. the agricultural vulnerability surface and the risk surface; the first one accounts for the peculiar vulnerability of a cropland to drought conditions and is constituted of three indicators (i.e. the soil suitability for crop production, the percentage of irrigation areas and the crop diversity index); the second surface tries to depict the linkage between areas hit by vegetation stress and areas where the impacts on the population may occur. The concept of risk surface is considered promising for it aims at translating the proved territorial relations between hazard and impacts into a spatial connection. It happens that these connections are renowned though not systematically analyzed in a GIS framework that set them for their transparent and objective use (Hillbruner, 2012). Three types of risk surfaces were tested and evaluated: (i) one obtained by implementing an accessibility model that takes into account the easiness to reach marketplaces; (ii) a second one obtained by applying a gravity model for user spatial choice among markets on the basis of each market influence; (iii) a third one in which the gravity model is combined with national market flow of goods.

A preliminary consideration regarding the three tested risk surfaces is the following: it can be inferred by examining the risk surface of first and second type that the differences between them are, sometimes, slight. This can be due to the author's choice in attributing the attractiveness factors of the implemented gravity model. As stated in previous study more attention should be devoted to the attribution of the attractiveness factors that, in the original Huff's probability function (see eq. [5]) were the size of the stores, and in the proposed model were replaced with the market importance factors. It must be said that the application attempts of consumers' choice models at the country level and in the context of developing countries are almost null; therefore necessary adaptations of these spatial models have still to be studied and verified.

The three resulting versions of the model, each obtained by using one of the three risk surfaces at a time, were applied to the hazard detected for two national case studies in the time frame 2006-2013: Niger and Mozambique. The final outputs, i.e. hazard values weighted with agricultural vulnerability and distributed over the risk surfaces, were evaluated qualitatively and quantitatively. The qualitative evaluation, performed in both cases, was made through the yearly comparison of the Final Alerts with the Fews Net products (food security assessment and outlooks maps) over the period 2008-2013. The quantitative evaluation was performed only in the case of Niger, by means of food security field survey data (i.e. WFP Food Security Assessment, FSA) of 2006-2013 that were retrieved by the author from WFP Niger country office during a field mission.

Both kinds of data that were used for evaluation purposes reports food insecurity conditions for country sub regions, directly measured on the basis of target households monitoring or estimated according to a set of indicators. Unfortunately the available time-series are quite short; moreover the reported food security levels are not disaster specific, and thus they could have been generated by a variety of causes unrelated to drought (e.g. floods, human conflicts). The above-mentioned conditions determine a bias in the evaluation of the presented model, i.e. the comparison between alerts resulted by the application of the model to the case studies and the food security status derived by Fews Net maps and WFP-FSA data. In fact the proposed vulnerability model is conceived to be applied only to drought events, which represent the hazard in the hypothetical risk equation. However it must be pointed out that validation data are, in particular for drought and food security, rather scarce and very difficult to be retrieved; the available evaluation data, both quantitative and qualitative, were then forcedly considered suited for the validation purposes of the presented study.

For what concerns the qualitative evaluation, it results that the risk surface of third type (i.e. obtained by the application of a gravity model combined with national market flow of goods) is more fitted to Fews Net evaluation data. The attempt of considering intra-national market trades proved to be effective even if, for the model to respond in a better way, further market characteristics (e.g. price trends) should be included in the analysis and frequently updated. For all the three tested risk surfaces it can be said that the model overestimates the food security alerts, providing correct alerts in years of verified famine crisis but also false alerts in years of proved minimal stress. It should be noted that the model could be calibrated to avoid the mentioned issue by being applied to other case studies and consequently by setting model parameters, such as introducing a threshold alert value for excluding negligible final alerts or reconsidering the ratio alerted pixels to cropland pixels, according to the outcomes of further comparisons with truth data.

As long as the quantitative evaluation is concerned, the results are highly variable among the departments, to which the model alerts originally given per risk surface units were aggregated in order to be comparable with Food Security Assessment data (i.e. FSA data are expressed in percentage of population in state of severe or moderate food insecurity), which are aggregated per administrative level 2 subdivisions of Niger (i.e. departments). It seems that, in general, the model alerts are in good accordance with truth data for the departments with a prevalence of cropland. In contrast, for those departments characterized by preponderance of breeding livelihoods, model results differ substantially from truth data. In order to further test the significance of the final alerts, produced by applying the model to the case studies, it has been decided to use the departments in place of the risk surfaces within the proposed model. The intention was to demonstrate that administrative subdivisions are inadequate to be used into a spatial risk assessment, as they are not the expression of any physical or socioeconomic meaning. The results of this operation show that, in general terms, alert levels are sometimes similar to that obtained with the use of the risk surfaces (i.e. of first and second type). However some of the departments (4 out of 36) are never alerted, when risk surfaces are not used, for any of the years of the available time series. Those departments proved instead to be in food insecurity conditions according to the truth data, therefore it can be pointed out that without introducing the risk surfaces those departments, characterized by a wide territory, are almost ignored by the model analysis. The need of identifying specific units to which the risk values should be attached (e.g. the risk surfaces in the proposed model) is thus confirmed by the results of the evaluation process.

A required further step in the model development would certainly be, as previously mentioned, the evaluation of the model alerts with other case studies and with longer time-series data. Unfortunately, the availability of reliable truth data related to food security highly depends on the country considered and on the source providing these data. As previously stated, another challenge would consist in the possibility of acquiring the same type of evaluation data for different countries in order to perform a uniform analysis over a set of countries experiencing recurrent food security crisis. Ideally the best evaluative scenario would consist in the possibility of use evaluation data at a higher detail level with respect to the size of the model alert units, which is a condition that is hard to be met.

Concerning possible improvements of the model, and of the considered early warning system itself, one would be to distinguish between hazard hitting cropland and grazing and to treat the resulting impacts in separate ways. This idea descends from the importance that the use of livelihoods is gaining among the field experts (Grillo, 2009; Hahn, Riederer, & Foster, 2009; Løvendal & Knowles, 2004). International organizations, NGOs and donors are working, in almost every developing country, at the definition of livelihood zones; the aim is to divide one territory into homogeneous areas from the point of view of living strategies (i.e. "the ways in which people obtain food and income and engage in trade"[35]) and to consider that people's vulnerability is strictly determined by their livelihoods (see Figure 30). That is, the livelihood zones should be included to some extent in the vulnerability measurement in the framework of a drought risk assessment.

Nonetheless the ultimate consideration about the usefulness of drought early warning systems result from the lessons learned after the 2011 Horn of Africa famine crisis. On that occasion signals were correctly interpreted by early warning systems and expert analyses were provided timely; however famine declaration was delayed for months (Hillbruner & Moloney, 2012). It can be concluded that early warning systems need, in general, to be further integrated with a variety of data, from detailed market analysis to livelihoods; in the meanwhile more efforts are to be invested into the translation of early warnings into early actions through the development of decision-support tools, of transparent funding chains and of a risk management culture (Bailey, 2013).

[35] http://www.fews.net/sectors/medios-de-vida

ANNEXES

Annex I - Matlab script for CDI

Matlab script for the calculation of the most produced crop and the CDI per country administrative level 2.

```
%% Extract prevalences in staples production and CDI for administrative
level 1 subdivision

%% Import the excel country files downloaded from CountrySTAT website

cd('folder')
listing = dir('folder');
myFolder = 'folder';

for k = 3:length(listing);
  filePattern = fullfile(myFolder, listing(k,1).name);
  MyXlsFiles = dir(filePattern);
  baseFileName = MyXlsFiles(3).name;
  fullFileName = fullfile(filePattern, baseFileName);
  fprintf(1, 'Now reading %s\n', fullFileName);
  [Countryname,txt] = xlsread(fullFileName,'B4:AZ2500');

%% Data preparation

Crops = txt(:,3);
Districts = txt(:,1);
[CropType, idxs] = unique(txt(:,3), 'first');
n = size(CropType,1);
DistrictName = unique(Districts);
a = size(DistrictName,1);
CropTypeChar = char(CropType);
chars_old = 'ÁÃÉÍÓÚáéèíïóúàãç-/''';
chars_new = 'AAEIOUaeeiiouaac    ';
[tf,loc] = ismember(CropTypeChar, chars_old);
CropTypeChar(tf) = chars_new( loc(tf) );

CropTypeOk = Crops(1:n);
CropTypeOkChar = char(CropTypeOk);
[tf,loc] = ismember(CropTypeOkChar, chars_old);
CropTypeOkChar(tf) = chars_new( loc(tf) );

%% Calculate average production per administrative level 1 per crop type

[DistrictName, idxsD, idxsD2] = unique(txt(:,1), 'first');
DistrictNameChar = char(DistrictName);
c = size(CropTypeChar,2);

for b = 1:n;
    FieldnameProd = (deblank(CropTypeChar(b,1:c)));
    FieldnameProd(~isstrprop(FieldnameProd,'alphanum')) = '';
    Production.(FieldnameProd)       =       Countryname(idxs(b):(idxs(b)+(a-
1)),3:end);
end

DistrictNameOk = DistrictName(idxsD2(1:a));

try
A = DistrictName(idxsD);
catch exception
    VettoreRiordina = ones(a,1);
```

```
    j = 1;
    for f = 1:a;
        VettoreRiordina(f) = idxsD2(j);
        j = j+n;
    end
    DistrictNameOk = DistrictName(VettoreRiordina);
    for b = 1:n;
        FieldnameProd = (deblank(CropTypeOkChar(b,1:c)));
        FieldnameProd(~isstrprop(FieldnameProd,'alphanum')) = '';
        Counter = (b:n:n*(a-1)+b);
        Production.(FieldnameProd) = Countryname(Counter,3:end);
    end
end

DistrictNameOk_ds = regexprep(DistrictNameOk, ' ', '_');

%% Build a structure hosting a field per each crop type

C = ones(n,a);
m=1;
for m = 1:n;
    FieldnameProd = (deblank(CropTypeChar(m,1:c)));
    FieldnameProd(~isstrprop(FieldnameProd,'alphanum')) = '';
    C(m,:) = nanmean(Production.(FieldnameProd),2);
end
C_headers = ones(n+1,a+1);
C_headers(1,:) = [1 idxsD'];
C_headers(2:n+1,2:a+1) = C;
C_headers(2:n+1,1) = (1:n)';

%% Calculate the most produced crop type per administrative level 1

[max_Prod_prova, indices] = max(C_headers(2:n+1,2:a+1),[],1);
CropTypeMax = CropType(indices);
Admin1_Crop_Max = [DistrictNameOk , CropTypeMax];

%% Save and convert output data into preferred format

saveFileName = fullfile(filePattern,'AdminProdMax.xls');
xlswrite(saveFileName, Admin1_Crop_Max);
clearvars -except listing myFolder

end
```

Annex II - CountrySTAT raw data

Example of the production data retrieved form CountrySTAT database per administrative level 1 of Mozambique.

Quantidade da produção de culturas primárias									
ano	item	Administrative Level 1	Administrative Level 1	2002	2003	2005	2006	2007	2008
item									
1112220	amendoim	2119	Niassa	1970	3140	2090	3980	2460	3940
1112220	amendoim	2112	Cabo Delgado	15080	23780	11400	9010	11080	10190
1112220	amendoim	2118	Nampula	57800	32180	46330	41230	49550	39860
1112220	amendoim	2122	Zambezia	7900	10610	7610	8190	11790	13170
1112220	amendoim	2121	Tete	6050	5920	8400	7580	9990	17370
1112220	amendoim	2115	Manica	1880	1860	2090	3180	3200	3230
1112220	amendoim	2120	Sofala	2020	1440	450	1650	2600	3150
1112220	amendoim	2114	Inhambane	5350	5030	5520	6510	7990	7140
1112220	amendoim	2113	Gaza	2930	3050	730	2210	1710	2380
1112220	amendoim	2116	Maputo Provinca	1090	450	1030	1050	930	2090
1120000	arroz	2119	Niassa	3800	3800	1500	2700	3000	4400
1120000	arroz	2112	Cabo Delgado	23500	22300	10800	14100	11500	6700
1120000	arroz	2118	Nampula	20800	13000	6300	9500	10000	12200
1120000	arroz	2122	Zambezia	27800	59000	29500	54300	61800	41400
1120000	arroz	2121	Tete	500	600	200	1100	300	400
1120000	arroz	2115	Manica	1200	500	700	1900	1500	800
1120000	arroz	2120	Sofala	7700	12200	3500	9800	10700	18700
1120000	arroz	2114	Inhambane	700	1200	1600	2400	1900	900
1120000	arroz	2113	Gaza	7300	4700	9800	1300	2100	2400
1120000	arroz	2116	Maputo Provinca	..	100	600	500	100	..
139810	batata doce	2119	Niassa	34890	..	43440	30700	19930	51310
139810	batata doce	2112	Cabo Delgado	11940	..	3160	3060	7910	6450

Quantidade da produção de culturas primárias									
ano	**item**	**Administrative Level 1**	**Administrative Level 1**	**2002**	**2003**	**2005**	**2006**	**2007**	**2008**
139810	batata doce	2118	Nampula	21830	..	14330	11100	8690	1760
139810	batata doce	2122	Zambezia	127120	..	80550	299650	205850	168890
139810	batata doce	2121	Tete	137110	..	159400	97400	288610	106440
139810	batata doce	2115	Manica	48740	..	36060	80690	177530	46480
139810	batata doce	2120	Sofala	22770	..	115260	93130	74530	91500
139810	batata doce	2114	Inhambane	6190	..	10100	4360	7830	4530
139810	batata doce	2113	Gaza	24000	..	25190	35360	55540	49690
139810	batata doce	2116	Maputo Provinca	21740	..	21350	22420	15010	39000
1112119	outros feijoes	2119	Niassa	1900	1900	1700	1500	1700	7400
1112119	outros feijoes	2112	Cabo Delgado	12100	2600	5200	4600	2500	4300
1112119	outros feijoes	2118	Nampula	16600	7700	8900	11500	11300	11500
1112119	outros feijoes	2122	Zambezia	14700	40700	26500	52200	71300	46100
1112119	outros feijoes	2121	Tete	2100	1400	400	600	1200	2800
1112119	outros feijoes	2115	Manica	2300	2100	700	1000	400	1500
1112119	outros feijoes	2120	Sofala	1300	2100	1300	1300	1800	1100
1112119	outros feijoes	2114	Inhambane	1200	800	200	1100	200	600
1112119	outros feijoes	2113	Gaza	2000	1600	400	900	1300	1400
1112119	outros feijoes	2116	Maputo Provinca	100	..	..	100	400	..
1112111	feijao manteiga	2119	Niassa	14900	17800	16300	19900	16300	22500
1112111	feijao manteiga	2112	Cabo Delgado	..	100	..	..	100	.
1112111	feijao manteiga	2118	Nampula	200	100	800	1300	3700	800
1112111	feijao manteiga	2122	Zambezia	5700	10000	7200	9500	14500	6700
1112111	feijao manteiga	2121	Tete	11700	9300	9800	11500	12400	15900
1112111	feijao manteiga	2115	Manica	2200	2300	4500	3800	3400	4000
1112111	feijao manteiga	2120	Sofala	100	300	1300	600	700	600
1112111	feijao manteiga	2114	Inhambane	..	..	100	..	200	.

Quantidade da produção de culturas primárias									
ano	**item**	**Administrative Level 1**	**Administrative Level 1**	**2002**	**2003**	**2005**	**2006**	**2007**	**2008**
1112111	feijao manteiga	2113	Gaza	500	900	10100	2600	2800	1600
1112111	feijao manteiga	2116	Maputo Provinca	300	200	300	300	100	400
1112112	feijÃo nhemba	2119	Niassa	2400	3200	3000	3700	1200	6400
1112112	feijÃo nhemba	2112	Cabo Delgado	8100	8800	8400	10200	12100	9600
1112112	feijÃo nhemba	2118	Nampula	21500	13200	12000	16500	20100	12500
1112112	feijÃo nhemba	2122	Zambezia	6200	13800	8100	8500	6000	10000
1112112	feijÃo nhemba	2121	Tete	5700	5400	6400	5300	4800	8700
1112112	feijÃo nhemba	2115	Manica	2900	6500	1500	2700	2800	2900
1112112	feijÃo nhemba	2120	Sofala	900	4900	1300	2400	2300	1900
1112112	feijÃo nhemba	2114	Inhambane	2400	3700	5200	12800	8900	4400
1112112	feijÃo nhemba	2113	Gaza	2800	3800	2200	6800	3300	4400
1112112	feijÃo nhemba	2116	Maputo Provinca	700	400	700	2200	700	1100
1112250	Gergelim	2119	Niassa	109	113	363	261	294	1135
1112250	Gergelim	2112	Cabo Delgado	2185	3459	6314	4610	3763	5494
1112250	Gergelim	2118	Nampula	6872	4951	7836	8727	5748	14117
1112250	Gergelim	2122	Zambezia	914	340	992	1335	930	983
1112250	Gergelim	2121	Tete	254	476	610	1390	1580	3465
1112250	Gergelim	2115	Manica	1949	1618	1260	1673	2161	3011
1112250	Gergelim	2120	Sofala	1626	2630	2692	2535	4298	12489
1112250	Gergelim	2114	Inhambane	..	..	17	12	..	2
1112250	Gergelim	2113	Gaza	..	..	..	..	..	..
1112250	Gergelim	2116	Maputo Provinca	1	..	4	18	4	..
1112230	Girassol	2119	Niassa	928	556	421	291	81	201
1112230	Girassol	2112	Cabo Delgado	139	21	8	26	18	28
1112230	Girassol	2118	Nampula	382	115	50	166	14	6
1112230	Girassol	2122	Zambezia	1314	766	310	898	2401	500
1112230	Girassol	2121	Tete	274	201	46	251	174	644

Quantidade da produção de culturas primárias									
ano	**item**	**Administrative Level 1**	**Administrative Level 1**	**2002**	**2003**	**2005**	**2006**	**2007**	**2008**
1112230	Girassol	2115	Manica	442	2038	187	506	3227	1895
1112230	Girassol	2120	Sofala	2	158	32	..	42	4
1112230	Girassol	2114	Inhambane	1	..	..	..	..	2
1112230	Girassol	2113	Gaza	1	74	..	..	.	1
1112230	Girassol	2116	Maputo Provinca	..	..	7	..	..	..
1131010	mandioca	2119	Niassa	58160	..	221820	53740	88530	427620
1131010	mandioca	2112	Cabo Delgado	269670	..	434400	300940	445610	313660
1131010	mandioca	2118	Nampula	1192210	..	1283720	1218290	1144170	896700
1131010	mandioca	2122	Zambezia	1105290	..	1601720	3094810	2322480	1814140
1131010	mandioca	2121	Tete	45030	..	69120	27480	24100	30270
1131010	mandioca	2115	Manica	103420	..	118990	197680	171520	103540
1131010	mandioca	2120	Sofala	81750	..	206700	144250	122630	153200
1131010	mandioca	2114	Inhambane	450540	..	666980	297960	442260	167520
1131010	mandioca	2113	Gaza	89750	..	137270	81620	156150	105410
1131010	mandioca	2116	Maputo Provinca	50210	..	41700	64570	41810	42530
01 11 1 9 1 0	mapira	2119	Niassa	11100	117500	6600	13100	7700	13100
01 11 1 9 1 0	mapira	2112	Cabo Delgado	24900	10300	30500	25900	17700	16800
01 11 1 9 1 0	mapira	2118	Nampula	43400	46000	16700	32700	21200	15200
01 11 1 9 1 0	mapira	2122	Zambezia	15800	25600	12100	14700	14000	17400
01 11 1 9 1 0	mapira	2121	Tete	7500	23700	9300	27400	22000	13600
01 11 1 9 1 0	mapira	2115	Manica	19400	11900	22200	45500	43800	15400
01 11 1 9 1 0	mapira	2120	Sofala	15500	32200	16500	39600	36200	31700
01 11 1 9 1 0	mapira	2114	Inhambane	500	39000	400	2300	3200	2300
01 11 1 9 1 0	mapira	2113	Gaza	100	400	200	600	900	800
01 11 1 9 1 0	mapira	2116	Maputo Provinca	..	1600	..	..	..	..
01 11 1 9 2 0	mexoeira	2119	Niassa	600	600	400	1200	900	400

Quantidade da produção de culturas primárias									
ano	**item**	**Administrative Level 1**	**Administrative Level 1**	**2002**	**2003**	**2005**	**2006**	**2007**	**2008**
01 11 1 9 2 0	mexoeira	2112	Cabo Delgado	700	400	300	100	200	2800
01 11 1 9 2 0	mexoeira	2118	Nampula	1200	500	600	2400	1500	800
01 11 1 9 2 0	mexoeira	2122	Zambezia	800	2800	2400	2300	3400	..
01 11 1 9 2 0	mexoeira	2121	Tete	5200	9700	7100	8200	10600	2800
01 11 1 9 2 0	mexoeira	2115	Manica	1400	2100	1500	3400	2400	2400
01 11 1 9 2 0	mexoeira	2120	Sofala	2000	4900	2200	4000	3600	4000
01 11 1 9 2 0	mexoeira	2114	Inhambane	100	0	100	200	500	200
01 11 1 9 2 0	mexoeira	2113	Gaza	100	500	600	500	1800	1300
01 11 1 9 2 0	mexoeira	2116	Maputo Provinca	100	..	..	..	..	..
01 11 1 2 0 0	milho	2119	Niassa	175200	159700	121700	222600	103800	170100
01 11 1 2 0 0	milho	2112	Cabo Delgado	85700	93100	80400	105000	85700	76100
01 11 1 2 0 0	milho	2118	Nampula	117400	89100	102500	124000	93900	100600
01 11 1 2 0 0	milho	2122	Zambezia	185200	298900	178800	213200	229000	209100
01 11 1 2 0 0	milho	2121	Tete	205200	183400	174000	260300	211800	238900
01 11 1 2 0 0	milho	2115	Manica	162800	172200	162200	204000	211900	187100
01 11 1 2 0 0	milho	2120	Sofala	76100	104100	52700	102500	96800	105100
01 11 1 2 0 0	milho	2114	Inhambane	18500	16700	18000	32500	29000	36900
01 11 1 2 0 0	milho	2113	Gaza	66900	56600	40800	102100	60900	63800
01 11 1 2 0 0	milho	2116	Maputo Provinca	21800	7600	10400	29300	10900	26500
01 15 00 10	tabaco	2119	Niassa	8393	19625	21630	23546	11009	14710
01 15 00 10	tabaco	2112	Cabo Delgado	258	..	3117	4454	341	..
01 15 00 10	tabaco	2118	Nampula	1138	2515	5461	4273	662	94
01 15 00 10	tabaco	2122	Zambezia	4179	5419	3741	31066	4916	5289
01 15 00 10	tabaco	2121	Tete	25635	19431	42685	28921	15518	24916
01 15 00 10	tabaco	2115	Manica	2413	3831	3685	202	1087	253
01 15 00 10	tabaco	2120	Sofala	94	231	156	220	30	22
01 15 00 10	tabaco	2114	Inhambane	198	46	1	192	31	..

Quantidade da produção de culturas primárias									
ano	**item**	**Administrative Level 1**	**Administrative Level 1**	**2002**	**2003**	**2005**	**2006**	**2007**	**2008**
01 15 00 10	tabaco	2113	Gaza	2	12	1	190	1	..
01 15 00 10	tabaco	2116	Maputo Provinca	260	21	365	1	..	977
01 16 1100	Algodão caroço	2119	Niassa	4290	1850	6559	7865	6794	..
01 16 1100	Algodão caroço	2112	Cabo Delgado	15317	13376	21677	30000	18965	..
01 16 1100	Algodão caroço	2118	Nampula	46202	21029	23816	34125	34020	..
01 16 1100	Algodão caroço	2122	Zambezia	4079	1889	4138	7468	10177	..
01 16 1100	Algodão caroço	2121	Tete	2203	2209	7905	11747	11622	..
01 16 1100	Algodão caroço	2115	Manica	493	11061	4001	5183	4690	..
01 16 1100	Algodão caroço	2120	Sofala	12085	2595	10587	12720	13511	..
01 16 1100	Algodão caroço	2114	Inhambane	6	101	..	11	150	..
01 16 1100	Algodão caroço	2113	Gaza	..	34	..	..	20	..
01 16 1100	Algodão caroço	2116	Maputo Provinca	..	..	..	..	..	..

Annex III - Developed tools

Agricultural vulnerability model

Input

Administrative level 0 boundaries (GADM): polygon feature

Global Map of Irrigation Area (GMIA): raster

Suitability for crop X (VMAP0): line feature

Crop Diversity Index (CDI): polygon feature

Tools

CLIP: The GMIA is clipped on the administrative level 0 boundaries.

Intermediate output : GMIA_clip

MOSAIC TO NEW RASTER: Suitability for different crops at administrative level 1 are mosaicked into a single raster.

Intermediate output : Suitability

RASTER CALCULATOR:

Null values are masked in the GMIA_Clip

Intermediate output : GMIA_masked

RASTER CALCULATOR(2) : the Suitability is combined with the GMIA_masked. The Map Algebra expression used is the following: Con(("%Suitability %" != 1) & ("%Suitability %" != 9), "% Suitability %" - Int("%GMIA_masked%"*0.05),"% Suitability %")

Intermediate output : SuitabilityAndGMIA

POLYGON TO RASTER : The Crop Diversity Index, previously obtained in shapefile format, is converted into raster.

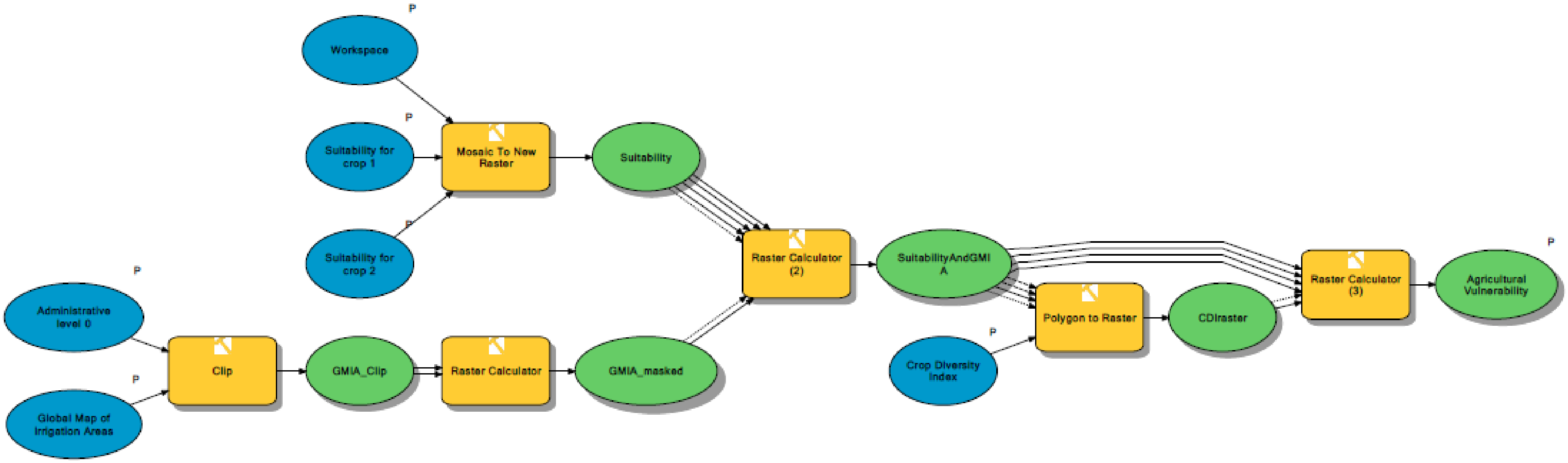
Intermediate output : CDIraster

RASTER CALCULATOR(3): The SuitabilityAndGMIA is weighted with the CDIraster by means of the following Map Algebra expression Con(("%SuitabilityAndGMIA%" != 1) & ("%SuitabilityAndGMIA%" != 9), "%SuitabilityAndGMIA%" - Con(1-"%CDIraster%" >= 0.5, 1, 0),"%SuitabilityAndGMIA%")

Final outputs

Agricultural Vulnerability: it is the combination of three vulnerability indicators and reports, per each pixel, a value of vulnerability in the range 1-9 where 0 is the less vulnerable, 8 is the most vulnerable and 9 identifies water.

Agricultural Vulnerability model



Accessibility model

Input

Elevation (GLOBE): raster

LandCover (GlobCover) : raster

Administrative level 0 boundaries (GADM): polygon feature

Market Locations: point feature

Transportation (VMAP0): line feature

Tools

CLIP, CLIP(2), CLIP(3) : Land Cover (global), Elevation (continental tile) and Market locations (global) are clipped on the administrative level 0 boundaries.

Intermediate outputs: GlobCover_Clip, GLOBE_Clip, Market_Locations_Clip

RECLASSIFY(2): clipped Land Cover (GlobCover_Clip) is reclassified in order to assign NoData value to certain classes (210 Water bodies, 220 Permanent Snow and ice, 230 NoData)

Intermediate output: GlobCover_REC

JOIN FIELD: a field containing the crossing time for each type of land cover is joined to the reclassified Land Cover. The GlobCover raster table was previously created with the Build Raster Attribute Table tool and the crossing time was added in a new field on the basis of the values reported in (F. Pozzi & Robinson, 2008).

Intermediate output: GlobCover_REC (2)

LOOKUP: it creates a new raster by looking up values of a specific field, in this case it creates a raster with the value of the just added crossing time field.

Intermediate output: Lookup_GlobCover

RESAMPLE(3): the Elevation raster is resampled to the Land Cover cell size (300 m)

Intermediate output: GLOBE_Resample

PROJECT RASTER: the Elevation raster is transformed in projected coordinates into the country correspondent UTM coordinate system (WGS84). The operation is needed to calculate the slope.

Intermediate output: GLOBE_Res_Proj

SLOPE: a slope raster is calculated on the basis of the Elevation raster. Output measurement is percent rise.

Intermediate output: Slope_output

PROJECT RASTER(2): the slope is transformed again into geographic coordinates.

Intermediate output: Slope_proj

RECLASSIFY: the values of the slope raster become weights, expressed as the percentage of the potential speed possible within each slope range, and are thus applied to reduce travel speed(F. Pozzi & Robinson, 2008).

Intermediate output: Reclass_Slope

FEATURE TO RASTER: transportation feature is converted into a raster at 300 m cell size on the basis of the previously added crossing time field, which contains a crossing time for each road type (F. Pozzi & Robinson, 2008).

Intermediate output: Roads

RASTER CALCULATOR: Roads and Lookup_GlobeCover are combined in order to obtain a unique raster with crossing time values for Land Cover and roads type. The Map Algebra expression used is the following: Con(IsNull("%Roads%"),"%Lookup_GlobeCover%","%Roads%")

Intermediate output: trcost

RASTER CALCULATOR:trcostraster is divided by theslope weight raster (Reclass_Slope). The Map Algebra expression used is the following: ("%trcost%" /"%Reclass_Slope%")*100

Intermediate output: trcost2

PROJECT RASTER(3): the trcost2 raster is transformed into projected coordinates in order to perform the Cost Allocation tool, which requires cell size expressed in meters.

Intermediate output: trcost2_ProjectRaster

COST ALLOCATION:Calculates for each cell its nearest Market source based on the least accumulative time over the trcost2_ProjectRaster raster.

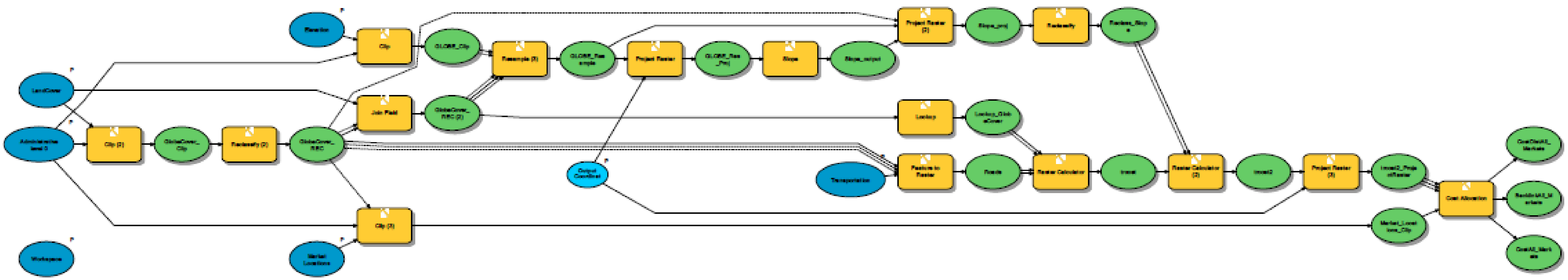
Final outputs

CostAll_Markets: this raster identifies the zone of each source location (Market Locations) that could be reached with the least time. Each cell has a value that corresponds to the nearest market in terms of time (min).

CostDistAll_Markets: identifies, for each cell, the least accumulative time over the cost surface (trcost2) to the identified source locations (Market Locations).

BacklinkAll_MArkets: the back-link raster contains values of 0 through 8, which define the direction or identify the next neighboring cell (the succeeding cell) along the least accumulative time path from a cell to reach its least cost source.

Accessibility model



Final Alert model

Input

Agricultural Vulnerability : raster

Vegetation anomalies : raster

Land Cover (GlobCover) : raster

Administrative level 0 boundaries (GADM) : polygon feature

Risk surface : raster

Tools

RESAMPLE: Agricultural Vulnerability is resampled to fit the Vegetation anomalies spatial resolution.

Intermediate outputs: Agricultural Vulnerability Resampled

CLIP, CLIP(2), CLIP(3): Vegetation anomalies, LandCover and Risk Surface are clipped on the administrative level 0 boundaries.

Intermediate outputs: Vegetation anomalies clipped, Land Cover clipped, Risk Surface clipped

RASTER TO POLYGON: the clipped Land Cover (Land Cover clipped) is converted into polygon feature on the basis of the raster values.

Intermediate output: Land Cover poly

RASTER CALCULATOR: NoData of Risk Surface are eliminated with Focal Statistics function implemented In the following expression: Con(IsNull("%Risk Surface%"), FocalStatistics("%Risk Surface%", NbrCircle(3, "CELL"), "MAJORITY"), "%Risk Surface%").

Intermediate output: Risk Surface filled

RASTER TO POLYGON (2): the clipped Risk Surface is converted into polygon feature on the basis of the raster values.

Intermediate output: Risk Surface poly

SELECT: the crop area is selected from the Land Cover. Identified ID values (ESAGlobCover classification) for crop subset are: 40, 50, 60, 70, 90, 100, 150, 170, 190, 200, 210, 220.

Intermediate output: Land Cover selection

DISSOLVE: features of Land Cover Selection are dissolved on the basis of the attribute that identifies the Land Cover classification.

Intermediate output: Land Cover selection D

CLIP(4): The Agricultural Vulnerability Resampled is clipped on the basis of the Land Cover Selection D.

Intermediate output: Agricultural Vulnerability clipped

RASTER CALCULATOR(2): the Vegetation Anomalies is weighted with the Agricultural Vulnerability clipped pixel by pixel with the following formula: Con((("%Vegetation Anomalies clipped%" > -400) & ("%Vegetation Anomalies clipped %" < 0)), ("%Vegetation Anomalies clipped %" * (9-"%Agricultural Vulnerability clipped%")))

Intermediate output: Alert per pixel

ZONAL STATISTICS AS TABLE, ZONAL STATISTICS AS TABLE (2): the number of alerted pixel, the number of crop pixel and the mean alert value per Risk Surface unit are retrieved from Alert per pixel raster and from the Agricultural Vulnerability clipped raster respectively.

Intermediate output: ZonalSt_TableAlert, ZonalSt_TableVeg

JOIN FIELD: the fields of the ZonalSt_TableAlert are joined to that of ZonalSt_TableVeg in order to compare their record values.

Intermediate output: ZonalSt_TableVeg_J

ADD FIELD: A field called PROP is added to ZonalSt_TableVeg_J in order to host a further calculation.

Intermediate output: ZonalSt_TableVeg_JAdd

CALCULATE FIELD: The PROP field of ZonalSt_TableVeg_JAdd is filled with the ratio between the alerted pixel and the crop pixel, for each record thus for each Risk Surface unit.

Intermediate output: ZonalSt_TableVeg(2)

JOIN FIELD: the fields of the ZonalSt_TableVEG(3) are joined to that of ZonalSt_TableAlert in order to compare their record values including the just added field.

Intermediate output: ZonalSt_TableAlert_J

ADD FIELD: A field called MEAN_PROP is added to ZonalSt_Table Alert_J in order to host a further calculation.

Intermediate output: ZonalSt_TableAlert_JAdd

CALCULATE FIELD: The MEAN_PROP field of ZonalSt_TableAlert_JAdd is filled with the multiplication between the mean alert value (MEAN) and the proportion of alerted value over the total crop pixel (PROP), for each record thus for each Risk Surface unit.

Intermediate output: ZonalSt_TableAlert_JAdd(2)

TABLE SELECT: The record of the ZonalSt_TableAlert_JAdd(2) with MEAN_PROP > 0,1 are selected for being assigned a Final Alert value in the output.

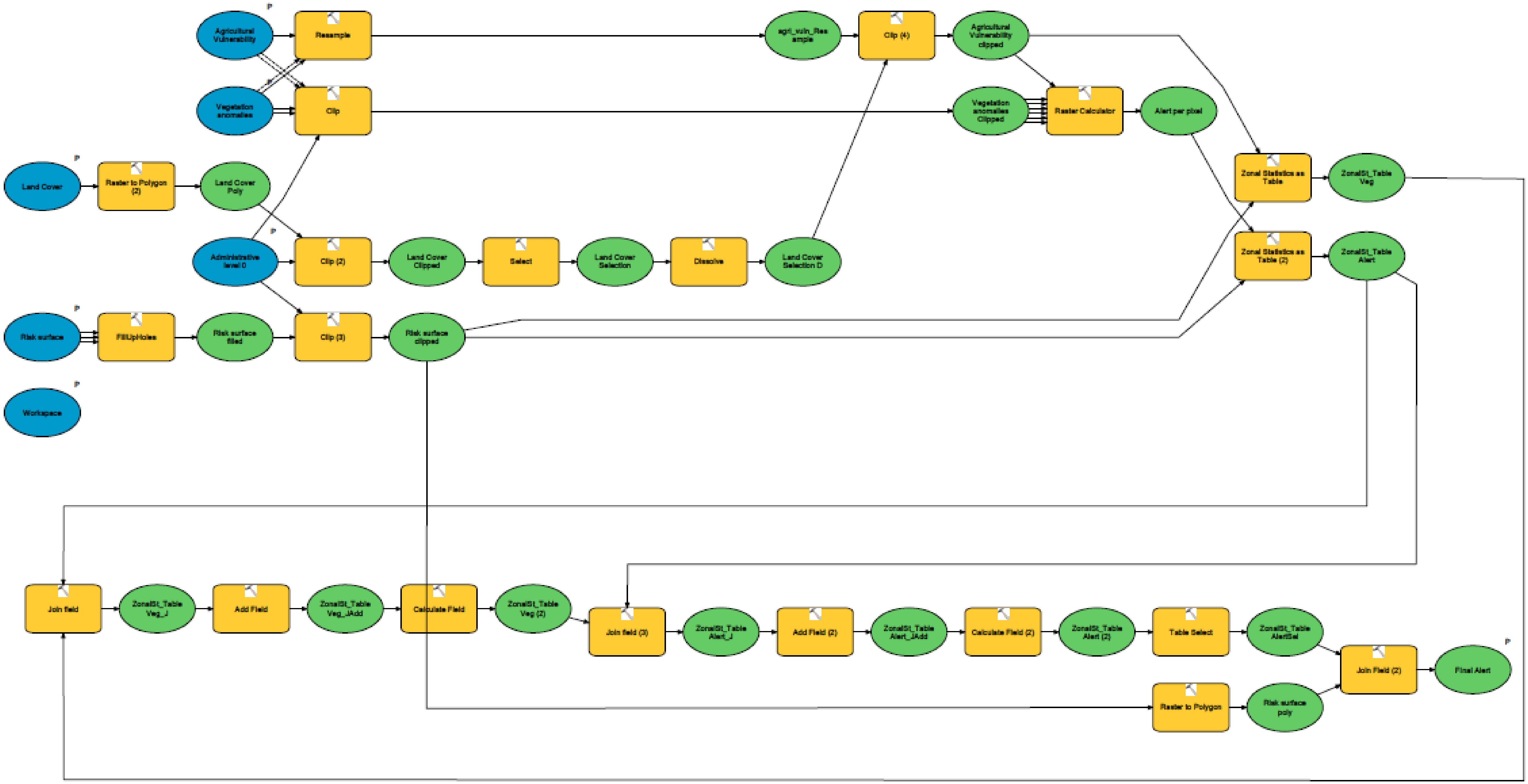
Intermediate output: ZonalSt_TableAlert_Sel

JOIN FIELD (2): The MEAN_PROP field of ZonalSt_TableAlert_Sel is joined to the Risk Surface poly.

Final outputs

Final Alert: this polygon feature identifies and shows, through appropriate symbology, the final alert values given per Risk Surface unit.

Final alert model



Huff step 1 model

Input

Sorted markets : point layer

Cost raster projected : raster

Tools

ITERATE FEATURE SELECTION: Iterates over features of a layer returning one record at a time that is used for further processing and a number (Value) which is the identifier of the record being used.

Intermediate outputs: I Sorted Markets

COST DISTANCE: For each of the Sorted Markets the cost distance is calculated taking into account the only market being used and the Cost Raster calculated with the *Accessibility model* and being reprojected into a suitable projected coordinate reference system.

Intermediate outputs: Cost Distance Gravity

GET FIELD VALUE: This tool returns, per record being used, the value of the Influence field of the Sorted Markets attribute table.

Intermediate outputs: Influence field value

RASTER CALCULATOR: Multiplies each of the pixel of the Cost Distance Gravity raster per the correspondent Influence value.

Final outputs

Utility%Value%: The raster contains the utility values for a specific market. This model returns as output as many Utility rasters as the number of records of the Sorted markets layer. Each of the output rasters is identified with the number stored in Value returned by the ITERATE FEATURE SELECTION tool.

Huff step 2 model

Input

Utility : rasters

Tools

RASTER CALCULATOR: Calculates the summation of all the Utility rasters provided in input.

Intermediate outputs: Summation

ITERATE RASTER: Given the workspace in which the Utility rasters are stored, this tool iterates over the rasters and returns one raster per iteration and its Name.

Intermediate outputs: Utility

RASTER CALCULATOR: Performs the calculation expressed by the modified Huff equation "%Utility%"/"%Summation%", that is the probability that the consumer located in a particular pixel would choose a market x.

Final outputs

Probability%Name%: The rasters contain the probability values calculated for a specific market at a time. This model returns as output as many Probability rasters as the number of records of the Sorted markets layer.

Huff step 3 model

Input

Probability: raster

Tools

HIGHEST POSITION: Determines on a cell-by-cell basis the position of the raster with the maximum value. The probability rasters being given in order it is possible to retrieve the market generating the maximum probability of choice in a particular cell. The result is a raster showing per cell an identifier of the input raster to which the maximum probability belongs.

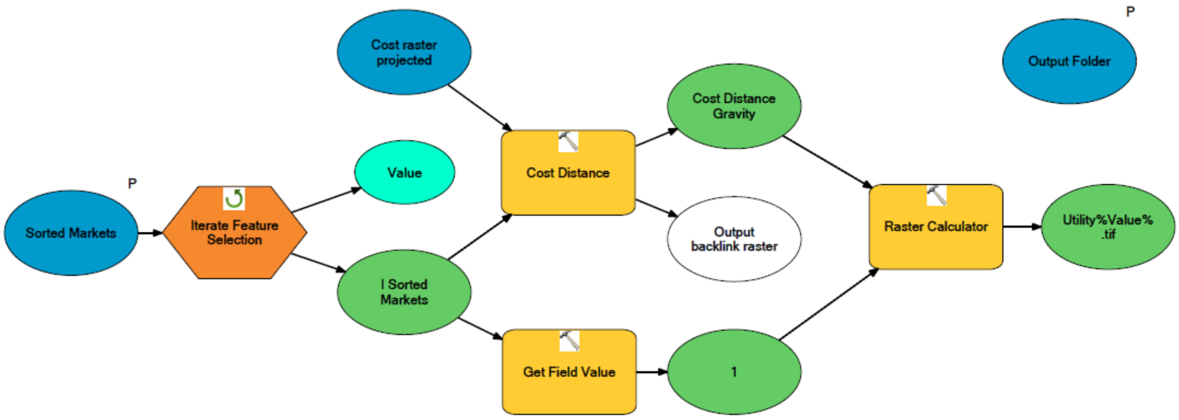
Intermediate outputs: Highest probability

RASTER TO POLYGON: The Highest probability raster is converted into polygon on the basis of the values of the raster identifying the markets.

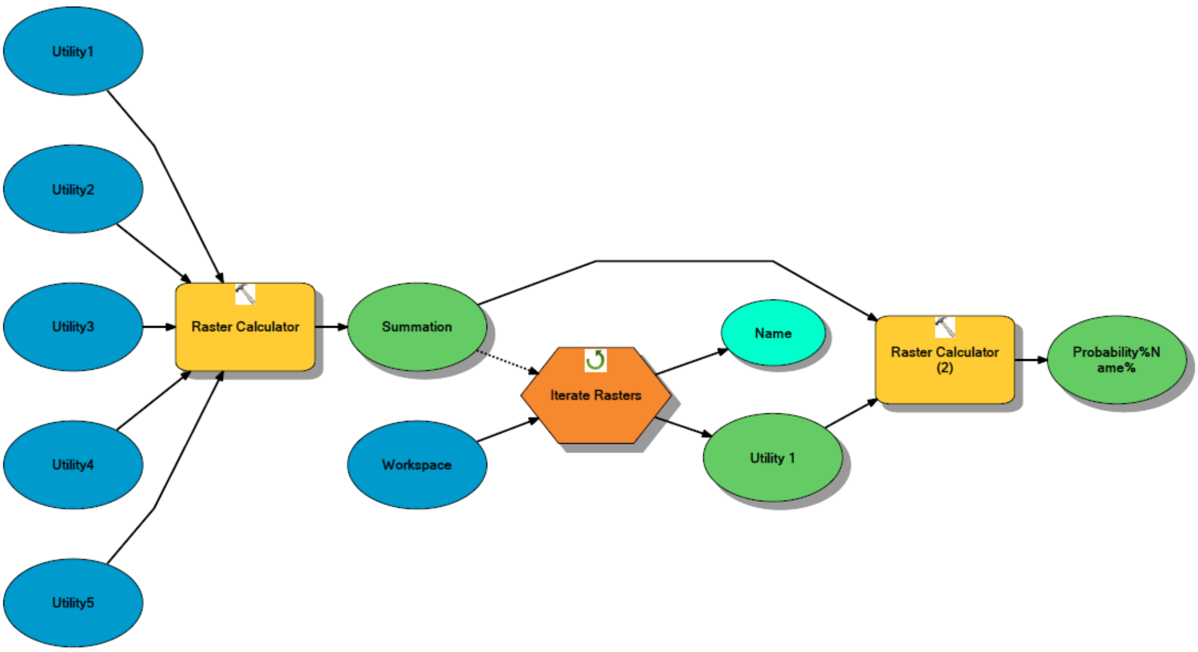
Final outputs

Highest probability Poly: The result is a polygon layer whose features are the risk surfaces iii, identified on the basis of the Huff modified formula.

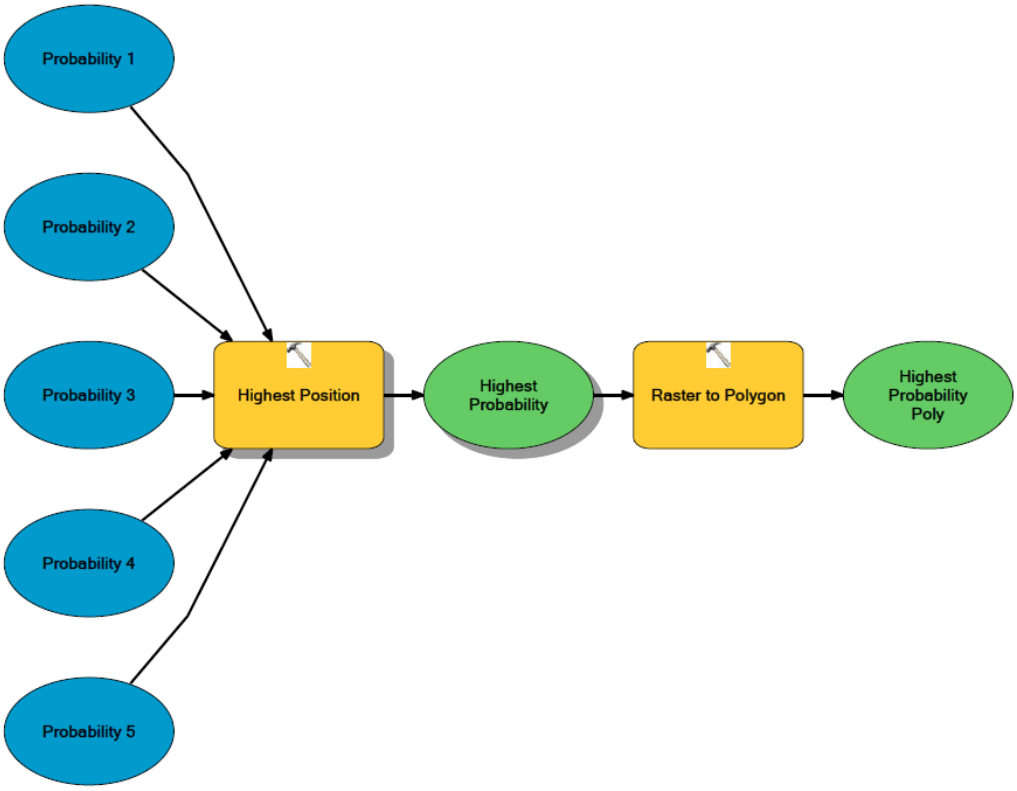
Huff step 1 model



Huff step 2 model



Huff step 3 model



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